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SUFFIELD REPORT

NO. 362

RHEOLOGICAL PROPERTIES OF POLYMER SOLUTIONS

PART I: SOLUTIONS OF K125/DPM (U)

by

S.J. Armour and M.D. Gauthier-Mayer

PCN 251SC-11

October 1986

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ABSTRACT

The rheology of the widely used simulant system, acryloid polymer K125-EA/dipropylene glycol monomethyl ether (DPM), has been investigated in detail using a variety of experimental techniques. Data is given for viscosity as a function of concentration and temperature and for first normal stress difference, storage and loss moduli as functions of concentration at 25°C. Various theoretical relationships between the material parameters are discussed in detail.

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INTRODUCTION

1. Solutions of the acryloid polymer K125-EA in dipropylene glycol monomethyl ether (DPM) have been widely used at the Defence Research Establishment Suffield (DRES) (1, 2) and at other laboratories (3) as simulants for chemical agents in equipment testing and procedural development. In order to determine if a given simulant system is a realistic choice, it is necessary to have detailed knowledge of the physical and rheological properties of both the agent and simulant systems. Warren (3) and Chenier and Hill (2) reported very limited rheological data for K125-EA/DPM solutions in which earlier formulations of K125-EA were used. With the availability of more complex test equipment, it is now possible to provide a detailed rheological characterization of the K125-EA/DPM system. The current TTCP accepted formulation of K125 (K125-EA lot 3-6326) is used throughout the study.

MATERIALS AND PREPARATION

2. The solvent, dipropylene glycol monomethyl ether, is a commercially available solvent manufactured by the Dow Chemical Company of Midland, Michigan. It is marketed under the trade name Dowanol DPM. Some relevant physical properties of DPM are given in Table I. The solvent was used directly as obtained from the manufacturer.

3. The polymer, designated K125-EA (lot 3-6326) is manufactured by Rohm and Haas. It consists of 82 mole percent methyl methacrylate, 12 mole percent ethyl acrylate and 6 mole percent butyl acrylate. It has a weight average molecular weight of 2.05×10^6 as determined by gel permeation chromatography, a number average molecular weight of 6×10^5 and a polydispersity of 3.41 (4).

4. The solutions were prepared by placing the solvent in a linear polyethylene bottle, adding the polymer, shaking vigorously to disperse the polymer and then rolling on a roller mixer for at least 24 hours. Solution preparation took place entirely at room temperature; heat was not applied to hasten dissolution of the polymer.

5. To obtain information on the reproducibility of solution preparation, two separate batches of solution were prepared for each concentration. The solutions designated A were prepared in January 1982 and those designated B in September 1984. A list of the solutions is given in Table II and Table III.

6. A series of very dilute K125/DPM solutions, designed by the suffix D, were prepared at DRES in July of 1982. These solutions are listed in Table IV.

7. In all cases, the resultant solutions were clear, colorless, and homogenous.

8. The densities of the K125/DPM solutions were measured at 25.0°C using an Anton Paar Model DMA 45 Digital Density Meter (5).

9. The surface tension was measured at 25.0°C using either the capillary rise or the bubble rise technique (5).

10. The Rheometrics Fluids Rheometer (RFR), a rotary rheometer, (operational procedures described in reference 6) was used to measure viscosity and first normal stress difference in steady shear, and storage and loss moduli in dynamic mode of the K125/DPM solutions. The instrument was used in the cone and plate configuration with 5 cm diameter plates and a 2.29 degree cone. All measurements were made at 25.0 ± 0.1°C.

11. For each material, steady shear measurements were made in the clockwise and counterclockwise directions on at least two separate samples and the results averaged. Dynamic measurements were also made on these samples, and the results averaged.

12. A second rotary rheometer, a Weissenberg R-17 Rheogoniometer (7), was also used to measure viscosity and first normal stress difference in steady shear of the K125/DPM solutions. The instrument was used in the cone and plate configuration with 5 cm diameter plates and either 1 or 2 degree cones. These measurements were made at 25 ± 1°C.

13. In an earlier comparison study (1), it was shown that Brookfield SyncroLectric viscometers gave viscosity data in good agreement with that obtained with the more difficult to operate rotational instruments. These Brookfield concentric cylinder instruments provided excellent temperature control to the sample and were ideally suited for studies of viscosity as a function of temperature. In this study a series of instruments (LVT, RVT, HAT and HBT) were used with a variety of spindle/cup combinations to measure the viscosity of the K125/DPM solutions as a function of temperature from 15 to 45°C, over as wide a shear rate range as practical.

14. Since the traditional method of characterizing solutions used in field trials is Ostwald viscosity, glass capillary viscometers of the Cannon-Fenske type (8) were used for this measurement.

RESULTS AND DISCUSSION

15. The densities and surface tensions of the K125/DPM A and B solutions are given in Table II and III respectively. In all cases, the density is within 2.1% of that of the solvent. The surface tension is also close to that of the solvent, being within 10.3%. Consequently, surface tension cannot be an important parameter in explaining the observed differences in

physical properties, such as drop size on breakup, between the solvent and the polymer/solvent solutions.

16. The Ostwald viscosities, η_{C-F}, of the K125/DPM A and B solutions, determined by glass capillary viscometers at 25.0°C are given in Tables II and III. Figure 1 shows a plot of η_{C-F} as a function of polymer concentration. For concentrations greater than 30 g/L, the viscosity increases rapidly with concentration (c) obeying the relationship

$$\eta_{C-F} = 2.64 \times 10^{-8} c^{5.33} \qquad [1]$$

17. The intrinsic viscosity, $[\eta]$, of a polymer/solvent system is defined as the ratio of the specific viscosity, η_{sp}, to the concentration at infinite dilution (8); that is,

$$[\eta] = \lim_{c \to 0} \frac{\eta - \eta_s}{c\eta_s} = \lim_{c \to 0} \frac{\eta_{sp}}{c} \qquad [2]$$

where η_s = solvent viscosity and $\eta_{sp} = (\eta/\eta_s - 1)$. When η_{sp}/c is plotted against c, a linear plot results corresponding to the equation

$$\frac{\eta_{sp}}{c} = [\eta] + k' [\eta]^2 c \qquad [3]$$

Figure 2 shows such a plot for the data of the D solutions, as listed in Table IV. For accuracy in extrapolating to c=0, solution concentrations were restricted to the range resulting in relative viscosities, η/η_s, between 1.1 and 1.5 as recommended by Markowitz (9). The value of $[\eta]$=155 cm^3/g is in reasonable agreement with that of 151 cm^3/g measured by Warren et al (3) for the earlier formulation of K125 in DPM.

18. Before starting detailed rheological testing of the K125/DPM

solutions, viscosity-shear rate curves were obtained for the A series solutions at 15, 20, 25, 35, 45 and 55° C using Brookfield viscometers. This data is given in Tables V-XI and a representative set of curves for solution 50A is shown in Figure 3. The curves are of similar shape which implies that temperature variations influence viscosity only by altering the zero shear viscosity, η_0, and the shear rate, $\dot{\gamma}_0$, at which the viscosity begins to decrease (10). Consequently, the data may be reduced to a single master curve. The method of superposition employed is that described by Mendelson (11). The shear stress (τ_{12}) - shear rate ($\dot{\gamma}$) curves are plotted at each temperature with the 25°C curve chosen as the reference curve. The values of the horizontal shift factors a_T at each temperature were obtained by choosing two shear rates, $\dot{\gamma}_A$ and $\dot{\gamma}_B$, on the reference temperature curve and shifting the corresponding points (constant shear stress) to the other curves to coincide with these shear rates. The values of a_T were calculated from

$$a_T = \dot{\gamma}(\text{ref})/\dot{\gamma}(T) \qquad (\tau_{12}) = \text{constant} \qquad [4]$$

The a_T values obtained at the two shear rates ($\dot{\gamma}_A$ and $\dot{\gamma}_B$) were averaged to minimize errors. Figure 4 shows the resultant master curve for solution 50A.

19. The values of the a_T factors for the A series of solutions is given in Table XII. The temperature dependence of the a_T factors was considered. An Arrhenius type equation of the form

$$a_T = B \exp (E_a/RT) \qquad [5]$$

where T = temperature (°K) and E_a = shift factor activation energy (Kcal/mole) gave satisfactory fits to the data (see Figure 5). The values of B and E_a are given in Table XII.

20. From the above discussion, it is evident that a general technique exists for predicting viscosity flow curve data at various temperatures. Equation 4 can be considered in terms of shear rate at any temperature, T, so that

$$\dot{\gamma}\,(T) = \dot{\gamma}(\mathrm{ref})/a_T \qquad [6]$$

where the corresponding shear stress is the same at the two shear rates. Consequently, given a set of shear stress-shear rate data at the reference temperature and a knowledge of a_T as a function of temperature, sets of τ_{12}-$\dot{\gamma}$-η data can be obtained at any desired temperature. This is particularly useful for field trial work, where experiments are carried out at a variety of temperatures.

21. A detailed characterization of the A and B series of the K125/DPM solutions was carried out using the Rheometrics Fluids Rheometer (RFR). The steady shear measurements were repeated for the B series using the Weissenberg R-17 rheogoniometer. The principal reasons for using both instruments were a) to provide a check on the accuracy of the measurements and b) to extend the shear rate range over as wide a range as possible. The RFR is equipped with a 100 g·cm torque transducer, which limits measurements to those falling in the torque range of 1 to 100 g·cm. For the majority of solutions considered here, this limitation, although serious, still permits data to be obtained over a reasonable shear rate range. With the Weissenberg Rheogonimeter, the range of the instrument can be adjusted by changing the torsion bar. Since a variety of torsion bars were available, it was hoped to extend the shear rate range by using this instrument.

22. Shear rate and viscosity data measured at 25.0°C using the Rheometrics Fluids Rheometer is given in Tables XIII - XVIII for the A series of solutions and Tables XIX - XXIV for the B series of solutions. The corresponding data obtained using the Weissenberg Rheogoniometer for the B series is given in Tables XXV to XXX. Viscosity versus shear rate curves are shown for the A series in Figures 6-11 and for the B series in Figures 12-17. The data obtained on the Rheometrics Fluids Rheometer and the Weissenberg Rheogoniometer are in excellent agreement (see Figures 12-17).

23. Several models are used to describe viscosity-shear rate behaviour (10). The simplest is the "power law" model in which the tilted straight line portion of the curve is described by a power law of the form

$$\eta = m\dot{\gamma}^{n-1} \qquad [7]$$

where η = viscosity (poise), $\dot{\gamma}$ = shear rate (sec^{-1}) and m and n are constants characteristic of the polymer solution. The values of the power law parameters obtained from a least squares fit of the data are given in Tables XXXI and XXXII.

24. This model, coupled with a knowledge of the zero shear rate viscosity, η_0, and the shear rate, $\dot{\gamma}_0$, at which the viscosity begins to decrease from η_0, can be used to adequately describe most non-Newtonian viscosity curves. Inspection of Figures 6-17 indicates that, in the majority of cases, measurements could not be made at low enough shear rates for the viscosity to reach a constant value, thus giving a definitive value of the zero shear rate viscosity, η_0. Values of η_0 were obtained by using the extrapolation method of Vinogradov and Malkin (12) in which log $1/\eta$ vs

shear stress (τ_{12}) was extrapolated to $\tau_{12}=0$. The shear rate, $\dot{\gamma}_0$, was arbitrarily chosen as the rate at which the viscosity dropped to 95% of its value at η_0. The values obtained for η_0 and $\dot{\gamma}_0$ are given Tables XXXI and XXXII.

25. A more complex model which gives a better fit to the complete viscosity-shear rate curve is the three parameter Carreau model (10). This model has the form

$$\frac{\eta - \eta_\infty}{\eta_0 - \eta_\infty} = [1 + (\lambda\dot{\gamma})^2]^{(n-1)/2} \qquad [8]$$

where η_0 = zero shear rate viscosity
η_∞ = infinite shear rate viscosity
λ = time constant
n = dimensionless power law index.

The data were fitted to the Carreau viscosity equation using a non linear least squares regression routine (13) with η_∞ set equal to zero. The values of the parameters n, η_0, and λ are given in Tables XXXIII and XXXIV. The values of η_0 and the power law index, n, calculated from the Carreau equation are in good agreement with the values of η_0, obtained by extrapolation, and n, obtained from the power law equation (see Tables XXXI and XXXII).

26. When the zero shear viscosity, η_0, and the Ostwald viscosity, η_{C-F}, as measured by glass capillary viscometers, are compared the agreement is excellent at low concentrations but diverges as the concentration increases

(see Tables II, III, XXXI and XXXII). The following relationship exists between the Ostwald viscosity and the zero shear viscosity

$$\eta_{C-F} = 0.894\ \eta_o^{0.9609} \qquad [9]$$

with a correlation coefficient, $R^2 = 0.9996$

27. First normal stress difference, N_1, data obtained at 25.0°C using the Rheometrics Fluids Rheometer is given in Tables XIV - XVIII for the A series of solutions and in Tables XX - XXIV for the B series of solutions. The corresponding data obtained using the Weissenberg Rheogoniometer for the B series is given in Tables XXVI to XXX. Plots of N_1 as a function of shear rate are given in Figures 7-11 for the A series and in Figures 13-17 for the B series. As observed for the viscosity-shear rate data, the first normal stress difference-shear rate data obtained on the Rheometrics Fluids Rheometer and the Weissenberg Rheogoniometer are in excellent agreement (see Figures 13-17).

28. A power law relationship is observed to exist between N_1 and the shear stress, τ_{12}

$$N_1 = \alpha\ \tau_{12}^{\beta} \qquad [10]$$

The values of the power law parameters α and β are given in Table XXXV and XXXVI.

29. Measurements were also made in the dynamic mode at 25.0°C using the Rheometrics Fluids Rheometer. The loss modulus, G'', and the storage modulus, G', are given as functions of the angular frequency, ω for the A series solutions in Tables XXXVII - XLII and for the B series solutions in

Tables XLIII - XLVIII. Figures 18 - 23 show plots of the dynamic viscosity, η',

$$\eta' = G''/\omega \qquad [11]$$

and G' as functions of ω for the A series and Figures 24-29 for the B series.

30. As in the case of the viscosity-shear rate data obtained in steady state experiments, the dynamic viscosity-frequency data can be described in terms of η_o, a characteristic frequency, ω_o, at which $\eta'(\omega)$ has decreased to 95% of its values at η_o and a power law slope observed at high frequencies. The values of ω_o and the power law parameters for the equation

$$\eta'(\omega) = a\omega^{b-1} \qquad [12]$$

are given in Tables XLIX and L.

31. A comparison between $\eta(\dot{\gamma})$ and $\eta'(\omega)$ indicate that both reach a limiting value of η_o as $\dot{\gamma}$ and ω approach zero and that both begin to decline at comparable values of $\dot{\gamma}$ and ω. However, η' falls off more rapidly with ω, than η with $\dot{\gamma}$, as is shown by the lower value of the power law slope, b. This decrease in $\eta'(\omega)$ is more pronounced for higher concentrations.

32. The Cox-Merz rule (14) was developed to obtain an improved relationship at high frequencies and shear rates. This rule predicts that the complex viscosity, η^*, should be comparable with viscosity, η, at equal values of ω and $\dot{\gamma}$.

$$\eta^*(\omega) = [(\eta'(\omega))^2+(G'(\omega)/\omega)^2]^{1/2}=\eta(\dot{\gamma})\Big|_{\dot{\gamma} = \omega} \qquad [13]$$

Figures 30 and 31 show a plot of $|\eta^*/\eta_o|$, η'/η_o and η/η_o as functions of reduced frequency β' and shear rate β, for the representative solutions 20A and 50A.

$$\beta' = (\eta_o - \eta_s)M\omega/cRT \qquad [14]$$

$$\beta = (\eta_o - \eta_s)M\dot{\gamma}/cRT \qquad [15]$$

where η_o= zero shear viscosity (poise)

η_s= solvent viscosity (poise)

M = molecular weight in g/mole of the polymer (M = 2.06 x 10^6 g/mole for K125)

R = universal gas constant 8.314 x 10^7 erg/deg mole

T = absolute temperature in deg K

c = concentration of the polymer solution in g/cm^3

As expected $\eta^*(\omega)$ follows $\eta(\dot{\gamma})$ more closely than $\eta'(\omega)$ but still falls off more rapidly with ω than η does with $\dot{\gamma}$.

33. The data given in Tables XXI, XXXII, XLIX and L, and presented in Figures 6-17 and 18-29 clearly show that dynamic data can be used to obtain a value of η_o and a good approximation to $\dot{\gamma}_o$. The decrease of $\eta'(\omega)$ or $\eta^*(\omega)$ with ω is more pronounced than that of $\eta(\dot{\gamma})$ with $\dot{\gamma}$. This is consistent with previous observations of polymethyl methacrylate (PMMA) solutions (15).

34. When $N_1/\dot{\gamma}^2$ and $2G'/\omega^2$ are plotted as functions of $\dot{\gamma}$ and ω, the $2G'/\omega^2$ curve falls off more rapidly with ω than the $N_1/\dot{\gamma}^2$ curve with $\dot{\gamma}$. Figure 32 shows these curves for a representative solution 50A. This is again consistent with previous observations of PMMA solutions (15).

35. Two separate batches of solution were prepared for each concentration to determine if reproducible solutions could be prepared. The data shown in Figures 6-11 and 18-23 for the A series of solutions and Figures 12-17 and 24-29 for the B series of solutions indicates that the method of solution preparation used does indeed yield essentially identical solutions. This observation is most encouraging in view of the difficulties other workers have had in preparing reproducible solutions (2,3). The fact that reproducible solutions can be prepared implies that for routine work a viscosity-shear rate curve, measured with a Brookfield viscometer, is sufficient to verify that the solution is indeed as expected. The additional rheological data required can then be obtained from the Tables given in this report. Thus, the very time consuming requirement of making a detailed rheological characterization of every solution used in a large field test program can be avoided.

CONCLUSIONS

1. The viscosity and first normal stress difference as a function of shear rate has been measured in steady shear for two separate series of solutions of K125/DPM using two different rheological instruments, a Rheometrics Fluids Rheometer and a Weissenberg Rheogoniometer R-17.

2. The storage and loss moduli as a function of frequency have also been measured in dynamic mode for the above solutions using a Rheometrics Fluids Rheometer.

3. Comparison between viscosity as a function of shear rate and complex viscosity as a function of frequency show that while both measurements go to η_o as $\dot{\gamma}$ and ω approach zero and give similar values for $\dot{\gamma}_o$ and ω_o, the complex viscosity decreases more rapidly as a function of frequency than the viscosity as a function of shear rate. A similar comparison between $N_1/\dot{\gamma}^2$ as a function of shear rate and $2G'/\omega^2$ as a function of frequency shows that $2G'/\omega^2$ falls off more rapidly with frequency than $N_1/\dot{\gamma}^2$ with

shear rate.

4. The intrinsic viscosity for K125 disolved in dipropylene glycol monomethyl ether is 155 cm^3/gm.

5. Using the method of preparation described in this report, reproducible solutions of K125/DPM can be prepared.

REFERENCES

1. S.J. Armour and M.D. Gauthier-Mayer, "Comparative Testing of Polymer Solutions (U), Part I: Preliminary Evaluation of a Rheometrics Fluids Rheometer", Suffield Report No. 365 (1983), UNCLASSIFIED.

2. C.L. Chenier and G.A. Hill, "Physical Properties of a Thickened Solvent", Suffield Report No. 435, (1979), UNCLASSIFIED.

3. B.C.H. Warren, J.A. Miles and M.G. Dalzell, "An Investigation of the Physical Properties of Thickened Simulants, Part I: Preliminary Studies", CDE TP 261, (1979), UNCLASSIFIED.

4. B.V. Gerber, TTCP-E3 correspondence DRD AR CLB-P 22 February 1980.

5. DRES Physical Chemistry Laboratory Procedures Manual, Volume I, in preparation.

6. DRES Physical Chemistry Laboratory Procedures Manual, Volume II, Rheometrics Fluids Rheometer, in preparation.

7. DRES Physical Chemistry Laboratory Procedures Manual, Volume III, Weissenberg R-17 Rheogoniometer, in preparation.

8. F.W. Billmeyer, "Textbook of Polymer Science", John Wiley, 1971.

9. H. Markowitz, "Polymer Rheology" Lecture Notes for Course 09-745, Carnegie Mellon University, 1978.

10. R.B. Bird, R.C. Armstrong and O. Hassager, "Dynamics of Polymer Liquids, Volume I", John Wiley, 1977.

11. R.A. Mendelson, "Prediction of Melt Viscosity Flow Curves at Various Temperatures for Some Olefin Polymers and Copolymers", Polymer Eng.Sci., 8, pp 235-240, (1968).

12. G.V. Vinogradov and A.Y. Malkin, "Temperature-Independent Viscosity Characteristics of Polymer Systems", J. Polymer Sci. A2, pp. 2357-2372, (1964).

13. ZXSSQ IMSL Library, International Mathematical and Statistical Libraries, Inc., Sixth Floor, NBC Building, 7500 Belaire Blvd., Houston, Texas, 77036.

14. W.P. Cox and E.H. Merz, "Correlation of Dynamic and Steady Flow Viscosities", J. Polymer Sci., 38, pp. 619-622, (1958).

15. K. Osaki, M. Tamura, T. Kotaka and M. Kurata, "Normal Stress and Dynamic Moduli in Polymer Solutions", J.Phys. Chem. 69, pp. 3642-3645 (1965).

TABLE I

PHYSICAL PROPERTIES OF DIPROPYLENE GLYCOL MONOMETHYL ETHER (DOWANOL DPM)

formula	$C_7H_{16}O_3$
molecular weight (g/mole)	148.2
boiling point (°C)	188.3*
density (g/cm^3) @ 25°C	0.9505
viscosity (cp) @ 25°C	3.565
surface tension (dynes/cm) @25°C	28.8*
vapour pressure (mmHg) @ 25°C	0.36*
solubility parameter (hildebrand)	9.3#

* Introducing Dowanol Solvents, Dow Chemical Company, Midland, Michigan

\# Polymer Handbook ed. Brandrup and Immergut Wiley-Interscience 1975

TABLE II

Density, Surface Tension & Ostwald Viscosity for K125/DPM Solutions

Series A Solutions

Solution Designation	Concentration (g/L)	Density (g/cm^3)	Surface Tension (dynes/cm)	Viscosity η_{C-F} (poise)
10A	9.57	0.952		0.139
20A	20.0	0.955		0.566
30A	30.0	0.957		2.03
36A	36.3	0.955	28.8	4.76
40A	40.0	0.959	28.7	8.43
45A	45.0	0.960		15.9
50A	50.0	0.962		30.8

TABLE III

Density, Surface Tension & Ostwald Viscosity for K125/DPM Solutions

Series B Solutions

Solution Designation	Concentration (g/L)	Density (g/cm^3)	Surface Tension (dynes/cm)	Viscosity η_{C-F} (poise)
20B	20.0	0.964	29.5	0.606
25B	25.0	0.965	29.7	1.12
30B	30.0	0.966	30.4	2.21
36B	36.3	0.968		5.49
40B	40.0	0.968		9.06
50B	50.0	0.970	31.8	34.5

TABLE IV

Densities and Viscosities of Dilute K125/DPM Solutions at 25.0°C

Concentration (g/dL)	Density (g/mL)	n_{C-F} (cpoise)	n_{sp}	n_{sp}/C (cm^3/g)
0	0.9505	3.565	0	
9.963	0.9504	4.184	0.1736	174.3
12.35	0.9507	4.350	0.2202	178.3
14.97	0.9505	4.550	0.2763	184.6
15.96	0.9507	4.620	0.2959	185.4
17.47	0.9506	4.740	0.3296	188.7

TABLE V

Shear Rate, Shear Stress & Viscosity Date for a 9.57 g/L Solution of K125/DPM (Solution 10A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} ($dynes/cm^2$)	η (poise)
T=15°C	27.6	5.17	0.188
	55.1	10.2	0.186
	90.	16.1	0.179
	225.	39.7	0.176
	450.	76.3	0.170
T=20°C	27.5	4.45	0.161
	55.1	8.56	0.161
	90.	14.0	0.155
	225.	34.3	0.152
	450.	66.2	0.147
T=25°C	27.5	3.92	0.143
	27.8	4.12	0.148
	55.0	7.88	0.143
	55.6	8.19	0.147
	90.0	12.1	0.134
	92.8	12.3	0.133
	225.	29.8	0.133
	450.	58.0	0.129
T=35°C	27.4	3.05	0.113
	54.9	6.20	0.111

TABLE VI

Shear Rate, Shear Stress & Viscosity Data for a 20.0 g/L Solution of K125/DPM (Solution 20A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} (dynes/cm^2)	η (poise)
T=15°C	3.92	3.38	0.86
	5.55	4.65	0.84
	7.84	6.47	0.83
	11.1	9.18	0.83
	15.7	12.8	0.81
	27.7	22.0	0.79
	39.2	30.5	0.78
	65.4	48.0	0.73
	92.4	65.8	0.71
	131.	91.5	0.70
T=20°C	7.85	5.60	0.71
	11.1	7.85	0.71
	15.7	11.1	0.71
	27.7	18.9	0.68
	39.2	26.3	0.67
	55.5	36.3	0.66
	65.4	41.6	0.64
	92.5	57.0	0.62
	130.	79.2	0.61
T=25°C	7.84	4.82	0.62
	11.1	6.85	0.62
	15.7	9.52	0.61
	27.8	16.5	0.59
	39.2	23.0	0.59
	55.5	31.7	0.57
	92.5	49.4	0.53
	131.	69.9	0.54

TABLE VI (continued)

Shear Rate, Shear Stress & Viscosity Data for a 20.0 g/L Solution of K125/DPM (Solution 20A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} ($dynes/cm^2$)	η (poise)
T=35°C	7.82	3.73	0.48
	11.1	5.32	0.48
	15.7	7.36	0.47
	27.7	12.8	0.46
	39.1	17.9	0.46
	55.4	24.6	0.44
	78.2	34.7	0.44
T=45°C	11.1	4.28	0.39
	15.7	5.85	0.37
	27.7	10.3	0.37
	39.1	14.4	0.37
	55.4	19.9	0.36
	78.3	27.7	0.35

TABLE VII

Shear Rate, Shear Stress & Viscosity Data for a 30.0 g/L Solution of K125/DPM (Solution 30A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} ($dynes/cm^2$)	η (poise)
T=15°C	1.39	4.86	3.49
	1.97	7.01	3.56
	2.78	9.63	3.46
	3.94	13.7	3.48
	5.57	18.6	3.35
	7.87	25.9	3.30
	11.1	35.5	3.19
	13.1	39.1	2.98
	18.6	54.6	2.94
	26.2	74.9	2.86
	46.4	126.	2.72
	65.6	174.	2.65
	92.8	235.	2.53
T=20°C	1.97	5.63	2.86
	2.79	7.90	2.83
	3.94	10.9	2.78
	5.58	15.1	2.71
	7.87	21.0	2.67
	11.2	28.9	2.59
	26.2	62.4	2.38
	46.5	103.	2.23
	65.6	142.	2.16
	92.9	190.	2.04
	131.	260.	1.98

TABLE VII (continued)

Shear Rate, Shear Stress & Viscosity Data for a 30.0 g/L Solution of K125/DPM (Solution 30A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} ($dynes/cm^2$)	η (poise)
	1.97	4.94	2.51
	2.79	6.50	2.33
	3.94	9.17	2.33
	5.57	12.6	2.27
	7.88	17.7	2.25
T=25°C	11.1	24.2	2.17
	15.8	33.8	2.14
	26.3	52.0	1.98
	46.4	87.3	1.88
	65.6	120.	1.82
	92.9	160.	1.72
	131.	216.	1.65
	2.78	4.66	1.68
	3.93	6.46	1.64
	5.56	9.12	1.64
	7.86	12.7	1.61
T=35°C	11.1	17.5	1.58
	15.7	24.4	1.55
	26.2	38.0	1.45
	27.8	41.5	1.49
	46.3	64.3	1.39
	65.5	89.5	1.37
	92.7	120.	1.29
	131.	162.	1.24

TABLE VII (continued)

Shear Rate, Shear Stress & Viscosity Data for a 30.0 g/L Solution of K125/DPM (Solution 30A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} ($dynes/cm^2$)	η (poise)
T=45°C	3.91	4.77	1.22
	5.56	6.84	1.23
	7.82	9.36	1.20
	11.1	13.2	1.19
	15.7	18.3	1.17
	27.8	31.4	1.13
	46.3	49.1	1.06
	92.6	92.5	1.00
T=55°C	5.54	5.12	0.92
	11.1	10.2	0.92
	27.7	24.6	0.89
	92.4	73.6	0.80

TABLE VIII

Shear Rate, Shear Stress & Viscosity Data for a 36.3 g/L Solution of K125/DPM (Solution 36A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} ($dynes/cm^2$)	η (poise)
T=15°C	0.56	5.08	9.10
	0.79	7.41	9.40
	1.40	12.5	8.93
	1.97	17.4	8.82
	2.79	23.9	8.85
	3.94	33.0	8.36
	6.57	50.8	7.72
	9.30	68.9	7.41
	13.2	94.5	7.19
	18.6	129.	6.92
	26.3	173.	6.56
	46.5	281.	6.04
	65.7	377.	5.73
T=20°C	0.79	5.76	7.30
	1.40	9.88	7.06
	1.97	13.8	6.98
	2.80	18.7	6.70
	3.95	26.4	6.68
	5.60	34.5	6.33
	9.33	54.0	5.78
	13.2	74.5	5.66
	18.7	102.	5.46
	26.3	135.	5.14
	46.7	222.	4.76
	65.8	291.	4.42
	93.3	395.	4.23

TABLE VIII (continued)

Shear Rate, Shear Stress & Viscosity Data for a 36.3 g/L Solution of K125/DPM (Solution 36A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} ($dynes/cm^2$)	η (poise)
	0.79	4.58	5.79
	1.40	7.77	5.55
	1.97	10.9	5.50
	2.80	15.	5.35
	3.95	20.6	5.23
T=25°C	5.60	28.5	5.08
	13.2	60.3	4.58
	18.7	82.1	4.40
	26.3	111.	4.22
	46.6	180.	3.86
	65.8	238.	3.61
	93.3	316.	3.39
	132.	414.	3.14
	1.40	5.19	3.72
	1.97	7.29	3.69
	2.79	10.1	3.63
	3.95	14.0	3.54
	5.58	19.2	3.45
	7.90	26.7	3.38
T=35°C	11.2	36.9	3.31
	18.6	57.2	3.07
	26.3	76.9	2.92
	46.5	129.	2.78
	65.8	168.	2.56
	93.0	228.	2.45
	132.	292.	2.22

TABLE VIII (continued)

Shear Rate, Shear Stress & Viscosity Data for a 36.3 g/L Solution of K125/DPM (Solution 36A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} ($dynes/cm^2$)	η (poise)
	1.97	5.32	2.70
	2.79	7.20	2.58
	3.94	10.0	2.55
	5.58	13.9	2.49
	7.88	19.5	2.47
T=45°C	11.2	26.5	2.37
	26.3	57.0	2.17
	46.5	95.7	2.06
	65.7	128.	1.95
	93.0	171.	1.84
	131.	225.	1.71
	2.78	5.50	1.98
	5.57	10.63	1.91
T=55°C	11.1	20.3	1.82
	46.4	74.0	1.60
	92.8	137.	1.48

TABLE IX

Shear Rate, Shear Stress and Viscosity Data for a 40.0 g/L Solution of K125/DPM (Solution 40A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} ($dynes/cm^2$)	η (poise)
T=15°C	0.56	9.78	17.5
	0.79	14.2	17.9
	1.40	22.7	16.2
	1.97	33.8	17.2
	3.29	52.3	15.1
	4.66	66.6	14.3
	6.58	97.5	14.8
	9.32	123.	13.2
	13.2	177.	13.4
	18.6	221.	11.9
	26.3	315.	12.0
T=20°C	0.56	7.23	12.9
	0.79	10.9	13.7
	1.40	17.4	12.4
	1.97	25.6	13.0
	2.80	33.1	11.8
	3.29	39.3	11.9
	4.67	50.6	10.9
	6.58	73.1	11.1
	9.34	94.4	10.1
	13.2	133.	10.1
	18.7	169.	9.07
	26.3	235.	8.94
	46.7	355.	7.60

TABLE IX (continued)

Shear Rate, Shear Stress and Viscosity Data for a 40.0 g/L Solution of K125/DPM (Solution 40A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} ($dynes/cm^2$)	η (poise)
	0.56	5.39	9.62
	0.79	8.03	10.0
	1.40	13.1	9.39
	1.97	19.6	9.93
	2.80	25.2	9.01
T=25°C	6.58	58.1	8.83
	9.33	73.4	7.87
	13.2	106.	8.06
	18.7	134.	7.17
	26.3	189.	7.19
	46.7	281.	6.02
	65.8	385.	5.86
	93.3	478.	5.13
	0.79	5.23	6.63
	1.40	8.30	5.93
	1.97	12.3	6.23
	2.80	16.2	5.80
	5.60	30.9	5.51
	6.57	37.0	5.64
T=35°C	9.34	48.7	5.21
	13.1	69.9	5.32
	18.7	90.8	4.87
	26.3	128.	4.85
	46.7	195.	4.17
	65.7	264.	4.02
	93.4	332.	3.55

TABLE IX (continued)

Shear Rate, Shear Stress and Viscosity Data for a 40.0 g/L Solution of K125/DPM (Solution 40A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} ($dynes/cm^2$)	η (poise)
T=45°C	1.40	5.69	4.07
	2.79	11.2	4.01
	5.58	21.6	3.87
	11.2	41.6	3.72
	13.2	49.1	3.71
	18.6	64.0	3.44
	26.5	92.5	3.50
	46.5	142.	3.06
	66.1	198.	3.00
	93.1	248.	2.66
	132.	336.	2.54

TABLE X

Shear Rate, Shear Stress and Viscosity Data for a 45.0 g/L Solution of K125/DPM (Solution 45A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} ($dynes/cm^2$)	η (poise)
T=15°C	0.28	9.86	35.2
	0.56	19.2	34.2
	1.32	42.2	32.0
	2.34	69.2	29.6
	3.30	95.3	28.9
	4.67	126.	27.0
	6.59	171.	26.0
	9.34	223.	23.8
	13.2	307.	23.3
	18.7	385.	20.6
T=20°C	0.28	6.97	24.9
	0.56	13.5	24.1
	1.40	31.8	22.7
	2.34	50.6	21.7
	3.32	70.3	21.2
	4.67	93.3	20.0
	6.64	128.	19.2
	9.35	166.	17.8
	13.3	225.	16.9
	18.7	287.	15.4
	26.6	377.	14.2
	46.7	567.	12.1

TABLE X (continued)

Shear Rate, Shear Stress and Viscosity Data for a 45.0 g/L Solution of K125/DPM (Solution 45A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} ($dynes/cm^2$)	η (poise)
T=25°C	0.28	5.12	18.3
	0.56	9.96	17.8
	0.80	14.8	18.6
	1.40	23.7	17.0
	1.99	34.8	17.5
	3.32	53.7	16.2
	4.66	71.2	15.3
	6.63	98.5	14.9
	9.32	128.	13.7
	13.3	176.	13.2
	18.7	223.	12.0
	26.5	297.	11.2
	46.6	443.	9.51
	66.3	570.	8.60
	133.	940.	7.09
T=35°C	0.56	5.89	10.5
	0.79	8.88	11.2
	1.40	14.5	10.3
	1.98	20.8	10.5
	2.80	27.8	9.91
	3.31	32.5	9.81
	6.61	61.2	9.25
	9.34	82.1	8.79
	13.2	113.	8.56
	18.7	148.	7.91
	26.5	198.	7.50
	47.7	301.	6.44
	66.1	386.	5.83

TABLE X (continued)

Shear Rate, Shear Stress and Viscosity Data for a 45.0 g/L Solution of K125/DPM (Solution 45A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} ($dynes/cm^2$)	η (poise)
	0.79	5.77	7.30
	1.40	9.58	6.83
	1.98	13.9	7.03
	2.81	18.6	6.63
	3.95	26.8	6.77
	5.61	35.5	6.33
	6.59	41.6	6.32
T=45°C	9.35	56.6	6.05
	13.2	78.5	5.96
	18.7	104.	5.54
	26.4	143.	5.42
	46.8	218.	4.67
	65.9	290.	4.40
	93.5	367.	3.91
	132.	466.	3.54

TABLE XI

Shear Rate, Shear Stress & Viscosity Data for a 50.0 g/L Solution of K125/DPM (Solution 50A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} ($dynes/cm^2$)	η (poise)
T=15°C	0.28	19.6	69.6
	0.56	37.7	67.0
	0.94	60.7	64.6
	2.35	134.	56.9
	3.33	176.	52.8
	4.69	233.	49.7
	6.67	305.	45.7
	9.39	406.	43.3
	13.3	514.	38.6
	18.8	660.	35.1
T=20°C	0.28	13.8	49.3
	0.56	26.8	47.6
	1.34	58.0	43.4
	2.34	96.3	41.1
	3.34	128.	38.2
	4.69	170.	36.3
	6.68	221.	33.1
	9.37	291.	31.0
	13.4	369.	27.6
	18.7	479.	25.6
	26.7	605.	22.6
	66.8	1155.	17.3

TABLE XI (continued)

Shear Rate, Shear Stress & Viscosity Data for a 50.0 g/L Solution of K125/DPM (Solution 50A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} ($dynes/cm^2$)	η (poise)
	0.28	10.0	35.5
	0.56	19.3	34.3
	1.33	42.0	31.5
	2.35	71.3	30.4
	3.34	95.9	28.8
T=25°C	4.69	129.	27.5
	6.67	170.	25.5
	9.39	223.	23.8
	13.3	288.	21.6
	18.8	372.	19.8
	26.7	465.	17.4
	46.9	702.	15.0
	66.7	852.	12.8
	0.28	5.56	19.9
	0.56	11.0	19.6
	0.80	16.0	20.1
	1.40	26.0	18.5
	1.99	37.3	18.7
	3.32	57.4	17.3
T=35°C	4.67	78.0	16.7
	6.65	106.	16.0
	9.33	140.	15.0
	13.3	188.	14.1
	18.7	241.	12.9
	26.6	315.	11.9
	46.7	466.	9.98
	66.5	577.	8.68
	133.	916.	6.89

TABLE XI (continued)

Shear Rate, Shear Stress & Viscosity Data for a 50.0 g/L Solution of K125/DPM (Solution 50A) as a Function of Temperature

	$\dot{\gamma}$ (sec^{-1})	τ_{12} ($dynes/cm^2$)	η (poise)
	0.56	6.85	12.2
	0.79	9.91	12.5
	1.40	16.4	11.7
	1.99	23.5	11.9
	2.81	32.1	11.4
	3.31	35.4	10.7
	6.62	68.4	10.3
T=45°C	9.36	94.0	10.0
	13.2	126.	9.51
	18.7	167.	8.93
	26.5	220.	8.32
	46.8	335.	7.16
	66.2	417.	6.30
	93.6	538.	5.75
	132.	659.	4.98

TABLE XII

a_T Factors for Series A Solutions of K125/DPM

Solution Designation	T (°C) 15	20	25	35	45	B	Ea (Kcal/mole)
10A	1.33	1.13	1.00				
20A	1.35	1.16	1.00	0.772	0.616	3.26×10^{-4}	4.80
30A	1.50	1.21	1.00	0.710	0.534	2.62×10^{-5}	6.30
36A	1.70	1.30	1.00	0.668	0.480	2.54×10^{-6}	7.71
40A	1.88	1.36	1.00	0.630	0.427	3.01×10^{-7}	8.99
45A	2.05	1.40	1.00	0.585	0.393	1.86×10^{-8}	10.0
50A	2.16	1.43	1.00	0.546	0.314	6.50×10^{-9}	11.3

TABLE XIII

SHEAR RATE AND VISCOSITY FOR A 20.0 g/L SOLUTION OF K125/DPM (SOLUTION 20A) RHEOMETRICS FLUIDS RHEOMETER DATA

SHEAR RATE (1/sec)	VISCOSITY (poise)	STANDARD DEVIATION
49.88	0.6006	0.0139
62.80	0.5932	0.0130
79.06	0.5823	0.0112
99.54	0.5728	0.0101
125.3	0.5611	0.0091
157.8	0.5485	0.0084
198.6	0.5339	0.0083
250.0	0.5211	0.0103
314.8	0.5037	0.0069
396.3	0.4863	0.0066

TABLE XIV

SHEAR RATE, VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE FOR A 30.0 g/L SOLUTION OF K125/DPM (SOLUTION 30A) RHEOMETRICS FLUIDS RHEOMETER DATA

SHEAR RATE (1/sec)	VISCOSITY (poise)	STANDARD DEVIATION	FIRST NORMAL STRESS DIFF. (cyre/cm**2)	STANDARD DEVIATION
10.00	2.362	0.028	-	-
12.59	2.318	0.004	-	-
15.85	2.284	0.003	-	-
19.95	2.241	0.011	-	-
25.12	2.198	0.001	-	-
31.63	2.151	0.002	-	-
39.81	2.092	0.001	-	-
50.12	2.031	0.001	180.4	44.
63.10	1.961	0.002	257.6	90.
79.44	1.892	0.006	374.9	84.
100.0	1.816	0.003	557.4	138.
125.9	1.734	0.028	895.3	164.
158.5	1.680	0.018	1106.	103.
199.6	1.613	0.025	1625.	49.
251.2	1.540	0.022	2154.	28.

TABLE XV

SHEAR RATE, VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE FOR A 36.3 g/L SOLUTION OF K125/DPM (SOLUTION 36A) RHEOMETRICS FLUIDS RHEOMETER DATA

SHEAR RATE (1/sec)	VISCOSITY (poise)	STANDARD DEVIATION	FIRST NORMAL STRESS DIFF. (dyne/cm**2)	STANDARD DEVIATION
5.000	5.242	0.074	-	-
6.295	5.161	0.058	-	-
7.925	5.049	0.047	-	-
9.977	4.950	0.040	-	-
12.56	4.827	0.041	-	-
15.81	4.690	0.038	-	-
19.91	4.545	0.029	101.2	1.1
25.06	4.383	0.027	148.1	1.0
31.55	4.221	0.018	215.1	5.3
39.72	4.056	0.007	323.6	20.
50.01	3.870	0.008	481.3	29.
62.96	3.673	0.023	664.5	65.
79.26	3.482	0.028	986.6	63.
99.78	3.320	0.039	1407.	49.
125.6	3.150	0.045	2015.	42.
158.2	2.978	0.050	2866.	72.
199.1	2.791	0.051	3754.	69.

TABLE XVI

SHEAR RATE, VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE FOR A 40.0 g/L SOLUTION OF K125/DPM (SOLUTION 40A) RHEOMETRICS FLUIDS RHEOMETER DATA

SHEAR RATE (1/sec)	VISCOSITY (poise)	STANDARD DEVIATION	FIRST NORMAL STRESS DIFF. (dyne/cm**2)	STANDARD DEVIATION
2.500	10.27	0.38	-	-
3.147	10.16	0.34	-	-
3.962	9.981	0.353	-	-
4.988	9.781	0.338	-	-
6.280	9.541	0.330	-	-
7.906	9.269	0.302	-	-
9.953	8.961	0.279	108.9	6.2
12.53	8.642	0.254	151.8	10.7
15.78	8.300	0.249	211.2	15.8
19.86	7.942	0.224	291.2	21.7
25.00	7.577	0.224	404.4	33.
31.48	7.231	0.207	566.7	48.
39.63	6.848	0.184	812.0	68.
49.89	6.433	0.159	1231.	89.
62.81	6.076	0.160	1719.	152.
79.07	5.704	0.141	2391.	201.
99.55	5.324	0.123	3276.	260.
125.3	4.953	0.110	4399.	337.
157.8	4.595	0.089	5764.	422.
198.6	4.291	0.130	7646.	1018.

TABLE XVII

SHEAR RATE, VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE FOR A 45.0 g/L SOLUTION OF K125/DPM (SOLUTION 45A) RHEOMETRICS FLUIDS RHEOMETER DATA

SHEAR RATE (1/sec)	VISCOSITY (poise)	STANDARD DEVIATION	FIRST NORMAL STRESS DIFF. (dyne/cm**2)	STANDARD DEVIATION
5.000	17.05	0.02	-	-
6.295	16.41	0.01	134.1	1.48
7.925	15.75	0.03	181.2	1.20
9.977	15.08	0.04	249.7	1.48
12.56	14.34	0.02	336.6	1.77
15.81	13.51	0.19	460.0	2.12
19.91	12.90	0.04	630.3	3.96
25.06	12.15	0.03	872.7	2.69
31.55	11.40	0.03	1239.	12.
39.72	10.66	0.01	1845.	1.
50.01	9.920	0.01	2503.	41.
62.96	9.197	0.02	3333.	16.
79.26	8.497	0.02	4439.	1.
99.78	7.822	0.04	5825.	62.
125.6	7.255	0.05	7931.	117.

TABLE XVIII

SHEAR RATE, VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE FOR A 50.0 g/L SOLUTION OF K125/DPM (SOLUTION 50A) RHEOMETRICS FLUIDS RHEOMETER DATA

SHEAR RATE (1/sec)	VISCOSITY (poise)	STANDARD DEVIATION	FIRST NORMAL STRESS DIFF. (dyne/cm**2)	STANDARD DEVIATION
0.5000	38.26	0.47	-	-
0.6295	37.74	0.14	-	-
0.7925	37.09	0.14	-	-
0.9977	36.55	0.13	-	-
1.256	35.61	0.13	-	-
1.581	34.94	0.17	-	-
1.991	34.07	0.13	-	-
2.506	32.95	0.15	91.2	7.2
3.155	31.74	0.13	124.5	4.5
3.972	30.54	0.13	162.6	4.1
5.001	29.17	0.12	219.6	2.8
6.295	27.77	0.08	287.7	8.8
7.926	26.31	0.08	391.5	11.5
9.978	24.85	0.08	526.1	16.0
12.56	23.34	0.06	711.2	16.2
15.82	21.86	0.06	961.2	22.
19.91	20.41	0.05	1310.	30.
25.07	18.94	0.04	1818.	50.
31.56	17.49	0.01	2626.	69.
39.73	16.12	-	3444.	82.
50.01	14.74	0.03	4455.	76.
62.97	13.46	0.01	5790.	83.
79.27	12.27	0.02	7462.	83.

TABLE XIX

SHEAR RATE AND VISCOSITY FOR A 20.0 g/L SOLUTION OF K125/DPM (SOLUTION 208) RHEOMETRICS FLUIDS RHEOMETER DATA

SHEAR RATE (1/sec)	VISCOSITY (poise)	STANDARD DEVIATION
49.88	0.6136	0.0021
62.80	0.6052	0.0034
79.06	0.5968	0.0046
99.54	0.5863	0.0048
125.3	0.5746	0.0068
157.8	0.5648	0.0053
198.6	0.5498	0.0037
250.0	0.5373	0.0054

TABLE XX

SHEAR RATE, VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE FOR A 25.0 g/L SOLUTION OF K125/DPM (SOLUTION 25B) RHEOMETRICS FLUIDS RHEOMETER DATA

SHEAR RATE (1/sec)	VISCOSITY (poise)	STANDARD DEVIATION	FIRST NORMAL STRESS DIFF. (dyne/cm**2)	STANDARD DEVIATION
10.00	1.318	0.082	-	-
12.59	1.303	0.083	-	-
15.85	1.290	0.084	-	-
19.95	1.272	0.077	-	-
25.12	1.250	0.076	-	-
31.63	1.230	0.076	-	-
39.81	1.202	0.076	-	-
50.12	1.176	0.073	-	-
63.10	1.148	0.070	-	-
79.44	1.119	0.065	-	-
100.0	1.089	0.062	178.9	76.
125.9	1.058	0.059	276.3	111.
158.5	1.024	0.055	384.0	155.
199.6	0.994	0.055	655.4	286.
251.2	0.967	0.047	942.3	291.
316.3	0.916	0.011	1151.	69.

TABLE XXI

SHEAR RATE, VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE FOR A 30.0 g/L SOLUTION OF K125/DPM (SOLUTION 308) RHEOMETRICS FLUIDS RHEOMETER DATA

SHEAR RATE (1/sec)	VISCOSITY (poise)	STANDARD DEVIATION	FIRST NORMAL STRESS DIFF. (cyne/cm**2)	STANDARD DEVIATION
10.00	2.462	0.047	-	-
12.59	2.417	0.027	-	-
15.85	2.379	0.028	-	-
19.95	2.330	0.023	-	-
25.12	2.278	0.016	-	-
31.63	2.220	0.015	-	-
39.81	2.157	0.020	-	-
50.12	2.093	0.018	134.6	2.6
63.10	2.028	0.023	196.4	9.8
79.44	1.965	0.023	293.5	22.
100.0	1.899	0.023	449.0	50.
125.9	1.825	0.031	727.1	93.
158.5	1.771	0.034	1194.	197.
199.6	1.708	0.024	1892.	173.
251.2	1.626	0.030	2465.	75.

TABLE XXII

SHEAR RATE, VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE FOR A 36.3 g/L SOLUTION OF K125/DPM (SOLUTION 36B) RHEOMETRICS FLUIDS RHEOMETER DATA

SHEAR RATE (1/sec)	VISCOSITY (poise)	STANDARD DEVIATION	FIRST NORMAL STRESS DIFF. (dyne/cm**2)	STANDARD DEVIATION
5.000	5.822	0.080	-	-
6.295	5.718	0.059	-	-
7.925	5.604	0.053	-	-
9.977	5.499	0.049	-	-
12.56	5.346	0.049	-	-
15.81	5.199	0.040	-	-
19.91	5.029	0.035	128.9	8.4
25.06	4.851	0.034	180.8	8.0
31.55	4.675	0.033	253.2	8.5
39.72	4.497	0.033	359.7	7.0
50.01	4.302	0.037	514.4	5.4
62.96	4.101	0.041	761.6	10.0
79.26	3.884	0.048	1186.	9.
99.78	3.719	0.047	1756.	48.
125.6	3.524	0.038	2593.	53.
158.2	3.320	0.040	3625.	81.
199.1	3.106	0.028	4792.	33.

TABLE XXIII

SHEAR RATE, VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE FOR A 40.0 g/L SOLUTION OF K125/DPM (SOLUTION 408) RHEOMETRICS FLUIDS RHEOMETER DATA

SHEAR RATE (1/sec)	VISCOSITY (poise)	STANDARD DEVIATION	FIRST NORMAL STRESS DIFF. (dyne/cm**2)	STANDARD DEVIATION
2.500	9.898	0.076	-	-
3.147	9.735	0.018	-	-
3.962	9.533	0.017	-	-
4.988	9.307	0.004	-	-
6.280	9.081	0.023	-	-
7.906	8.812	0.023	-	-
9.953	8.516	0.026	-	-
12.53	8.202	0.013	-	-
15.78	7.878	0.003	155.0	5.6
19.86	7.553	0.005	221.3	5.4
25.00	7.217	0.015	312.1	5.4
31.48	6.903	0.018	442.2	7.5
39.63	6.566	0.037	624.1	10.7
49.89	6.224	0.051	887.4	11.8
62.81	5.868	0.070	1298.	19.
79.07	5.532	0.085	1986.	10.6
99.55	5.219	0.098	2866.	4.2
125.3	4.872	0.113	3968.	46.
157.8	4.526	0.120	5351.	102.
198.6	4.214	0.129	7143.	195.
250.1	3.889	0.102	9195.	231.

TABLE XXIV

SHEAR RATE, VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE FOR A 50.0 g/L SOLUTION OF K125/DPM (SOLUTION 508) RHEOMETRICS FLUIDS RHEOMETER DATA

SHEAR RATE (1/sec)	VISCOSITY (poise)	STANDARD DEVIATION	FIRST NORMAL STRESS DIFF. (dyne/cm**2)	STANDARD DEVIATION
0.5000	41.00	1.60	-	-
0.6295	40.18	1.43	-	-
0.7925	39.53	1.47	-	-
0.9977	39.04	1.41	-	-
1.256	38.14	1.24	-	-
1.581	37.21	1.27	-	-
1.991	36.20	1.16	-	-
2.506	34.88	1.02	-	-
3.155	33.41	1.02	-	-
3.972	31.95	1.03	134.5	7.1
5.001	30.55	0.87	190.6	10.4
6.295	29.01	0.83	261.1	10.0
7.926	27.49	0.77	360.3	7.6
9.978	25.95	0.72	492.0	6.1
12.56	24.37	0.64	672.9	7.9
15.82	22.78	0.56	914.6	8.0
19.91	21.22	0.50	1239.	8.
25.07	19.69	0.45	1681.	12.
31.56	18.20	0.39	2295.	4.
39.73	16.77	0.33	3173.	30.
50.01	15.39	0.29	4253.	37.
62.97	14.06	0.27	5616.	79.
79.27	12.80	0.25	7323.	109.
99.80	11.56	0.21	9343.	49.

TABLE XXV

Shear Rate and Viscosity for a 20.0 g/L Solution of K125/DPM (Solution 20B) Weissenberg Rheogoniometer Data

Shear Rate (1/sec)	Viscosity (poise)	Standard Deviation
5.46	0.643	0.015
6.88	0.643	0.021
8.66	0.642	0.018
10.90	0.641	0.023
13.72	0.640	0.030
17.28	0.638	0.021
21.75	0.635	0.006
27.38	0.631	0.012
34.47	0.625	0.008
43.40	0.617	0.006
54.64	0.608	0.010
68.78	0.598	0.013
86.59	0.586	0.005
109.01	0.574	0.006
137.24	0.561	0.004
172.78	0.548	0.012
217.51	0.534	0.003
273.83	0.521	0.006
344.73	0.508	0.002

TABLE XXVI

Shear Rate, Viscosity & First Normal Stress Difference for a 25.0 g/L Solution of K125/DPM (Solution 25B) Weissenberg Rheogoniometer Data

Shear Rate (1/sec)	Viscosity (poise)	Standard Deviation	First Normal Stress Diff. (dynes/cm^2)	Standard Deviation
5.46	1.12	0.05		
6.88	1.13	0.04		
8.66	1.11	0.04		
10.90	1.12	0.01		
13.72	1.11	0.03		
17.28	1.10	0.02		
21.75	1.08	0.01		
27.38	1.08	0.01		
34.47	1.06	0.01		
43.40	1.04	0.01		
54.64	1.02	0.01		
68.78	0.99	0.01		
86.59	0.97	0.02		
109.01	0.94	0.01	138	44
137.24	0.91	0.01	189	42
172.78	0.88	0.01	266	50
217.51	0.86	0.01	745	90
273.83	0.83	0.02	1030	52
344.73	0.81	0.00		

TABLE XXVII

Shear Rate, Viscosity & First Normal Stress Difference for a 30.0 g/L Solution of K125/DPM (Solution 30B) Weissenberg Rheogoniometer Data

Shear Rate (1/sec)	Viscosity (poise)	Standard Deviation	First Normal Stress Diff. (dynes/cm^2)	Standard Deviation
2.74	2.43	0.00		
3.45	2.27	0.09		
4.34	2.27	0.10		
5.46	2.28	0.03		
6.88	2.23	0.08		
8.66	2.18	0.03		
10.90	2.16	0.08		
13.72	2.11	0.06		
17.26	2.09	0.03		
21.75	2.03	0.04		
27.38	1.99	0.04		
34.47	1.94	0.05		
43.40	1.89	0.07	100	4
54.64	1.82	0.05	140	2
68.78	1.76	0.05	200	9
86.59	1.70	0.05	279	12
109.01	1.63	0.07	416	22
137.24	1.59	0.02	792	80
172.78	1.55	0.02	1363	136
217.51	1.48	0.01	1992	92
273.83	1.40		2553	

TABLE XXVIII

Shear Rate, Viscosity & First Normal Stress Difference for a 36.3 g/L Solution of K125/DPM (Solution 36B) Weissenberg Rheogoniometer Data

Shear Rate (1/sec)	Viscosity (poise)	Standard Deviation	First Normal Stress Diff. (dynes/cm^2)	Standard Deviation
0.87	6.06			
1.09	5.99			
1.37	5.70			
1.73	5.64			
2.18	5.63			
2.74	5.39	0.44		
3.45	5.23	0.50		
4.34	5.19	0.36		
5.46	5.21	0.22		
6.88	5.12	0.22		
8.66	5.04	0.20		
10.90	4.90	0.17		
13.72	4.73	0.16		
17.28	4.57	0.19		
21.75	4.40	0.20	132	15
27.38	4.32	0.28	181	22
34.47	4.12	0.11	264	28
43.40	4.01	0.07	372	25
54.64	3.84	0.06	527	46
68.78	3.62	0.06	810	43
86.59	3.46	0.07	1275	61
109.01	3.26	0.07	1980	190
137.78	3.00	0.15	2796	190
172.78	2.87	0.08	3688	378
217.51	2.61	0.03	4688	379

TABLE XXIX

Shear Rate, Viscosity & First Normal Stress Difference for a 40.0 g/L Solution of K125/DPM (Solution 40B) Weissenberg Rheogoniometer Data

Shear Rate (1/sec)	Viscosity (poise)	Standard Deviation	First Normal Stress Diff. (dynes/cm^2)	Standard Deviation
8.66	8.86	0.10		
10.90	8.62	0.01	116	2.5
13.72	8.15	0.12	159	3.5
17.28	7.74	0.05	216	1.0
21.75	7.46	0.04	303	9.7
27.38	7.10	0.03	418	1.0
34.47	6.80	0.05	588	
43.40	6.40	0.02	775	
54.64	6.02	0.02	1198	17
68.78	5.73	0.04	1859	96
86.59	5.38	0.02	2788	108
109.01	5.05	0.02	3814	330
137.24	4.73	0.04	5273	502
172.78	4.36	0.13	6832	1078
217.51	4.05	0.15	8934	1365

TABLE XXX

Shear Rate, Viscosity & First Normal Stress Difference for a 50.0 g/L Solution of K125/DPM (Solution 50B) Weissenberg Rheogoniometer Data

Shear Rate (1/sec)	Viscosity (poise)	Standard Deviation	First Normal Stress Diff. (dynes/cm²)	Standard Deviation
0.27	44.97	1.39		
0.35	41.55	4.94		
0.43	41.33	6.10		
0.55	41.40	6.58		
0.69	41.06	6.33		
0.87	42.56	1.92		
1.09	42.25	2.80		
1.37	41.44	2.50		
1.73	40.61	2.87		
2.18	39.09	3.53		
2.74	36.72	0.43		
3.45	34.75	0.90		
4.34	32.66	1.30	152	33
5.46	30.56	1.36	192	16
6.88	29.28	0.49	268	35
8.66	26.94	0.73	400	56
10.90	25.14	0.55	525	7.8
13.72	23.88	0.19	754	46
17.28	22.00	0.39	1049	60
21.75	20.19	0.59	1429	135
27.38	18.97	0.71	2047	286
34.47	17.59	0.41	2758	283
43.40	16.52	0.37	3751	362
54.64	15.07	0.08	5123	337
68.78	13.89	0.08	6561	647
86.59	12.36	0.88	8712	710
109.0	11.19	0.77	11220	1032
137.2	10.12	0.76	14830	1032
172.8	8.60		19920	
217.5	7.55		28020	

TABLE XXXI

Parameters* for the Power Law Equation for K125/DPM Solutions

Series A Solutions

Solution Designation	η_0 (poise)	$\eta = m\dot{\gamma}^{n-1}$ m	n	$\dot{\gamma}_0$ (sec^{-1})
10A	0.135			
20A	0.646	1.02	0.878	43.0
30A	2.50	3.82	0.837	9.00
36A	5.60	8.99	0.782	4.00
40A	10.9	18.9	0.723	2.50
45A	20.0	32.3	0.695	1.25
50A	40.3	55.9	0.659	0.500

* data measured at 25.0°C with Rheometrics Fluids Rheometer

TABLE XXXII

Parameters* for the Power Law Equation for K125/DPM Solutions

Series B Solutions

Solution Designation	η_o (poise)	$\eta=m\dot{\gamma}^{n-1}$ m	n	$\dot{\gamma}_o$ (sec^{-1})
20B	0.645	0.965	0.893	60.0
25B	1.36	1.98	0.869	11.0
30B	2.61	3.67	0.855	9.0
36B	6.26	10.1	0.780	3.75
40B	10.6	18.2	0.724	2.50
50B	42.9	59.8	0.650	0.600

* data measured at 25.0°C with the Rheometrics Fluids Rheometer

TABLE XXXIII

Parameters* for the Carreau Viscosity Equation for K125/DPM Solutions

Series A Solutions

Solution Designation	η_o (poise)	λ (1/sec)	n
20A	0.614	0.013	0.861
30A	2.38	0.047	0.826
36A	5.28	0.085	0.781
40A	10.3	0.128	0.741
45A	18.0	0.141	0.692
50A	37.5	0.422	0.703

* data measured at 25.0°C with a Rheometrics Fluid Rheometer

TABLE XXXIV

Parameters* for the Carreau Viscosity Equation for K125/DPM Solutions

Series B Solutions

Solution Designation	η_0 (poise)	λ (1/sec)	n
20B	0.631	0.017	0.891
25B	1.33	0.045	0.867
30B	2.47	0.045	0.833
36B	5.87	0.088	0.787
40B	9.88	0.144	0.755
50B	40.2	0.451	0.697

* data measured at 25.0°C with a Rheometrics Fluids Rheometer

TABLE XXXV

Parmeters* for the Equation $N_1 = \alpha\tau_{12}^{\beta}$ for K125/DPM Solutions

Series A Solutions

Solution Designation	r^2	α	β
30A	0.995	2.96×10^{-2}	1.89
36A	1.00	1.14×10^{-2}	2.02
40A	0.999	1.74×10^{-2}	1.93
45A	0.998	1.74×10^{-2}	1.91
50A	0.997	2.62×10^{-2}	1.82

* data measured at 25.0°C with a Rheometrics Fluids Rheometer

TABLES XXXVI

Parameters* for the Equation $N_1 = \alpha \tau_{12}^{\beta}$ for K125/DPM Solutions

Series B Solutions

Solution Designation	r^2	α	β
25B	0.991	3.19×10^{-2}	1.86
30B	0.996	5.80×10^{-3}	2.16
36B	0.998	9.58×10^{-3}	2.04
40B	0.999	7.99×10^{-3}	2.04
50B	0.999	1.10×10^{-2}	1.93

* data measured at 25.0°C with a Rheometrics Fluid Rheometer

TABLE XXXVII

FREQUENCY, LOSS MODULUS(G'') AND STORAGE MODULUS(G') FOR A 20.0 g/L SOLUTION OF K125/DPM (SOLUTION 20A) RHEOMETRICS FLUIDS RHEOMETER DATA

FREQUENCY (1/sec)	G'' (dyne/cm**2)	STANDARD DEVIATION	G' (dyne/cm**2)	STANDARD DEVIATION
25.00	14.49	0.31	2.433	0.130
31.47	17.89	0.36	3.457	0.124
39.62	22.03	0.43	4.922	0.131
49.88	27.08	0.48	7.016	0.155
62.80	32.87	0.59	9.993	0.201
79.06	39.75	0.68	14.22	0.30
99.54	47.78	0.76	20.33	0.47
125.3	56.74	0.79	29.18	0.74
157.8	66.42	0.54	41.87	1.26
198.6	75.27	0.20	61.00	1.57

TABLE XXXVIII

FREQUENCY, LOSS MODULUS(G'') AND STORAGE MODULUS(G') FOR A 30.C g/L SOLUTION OF K125/DPM (SOLUTION 30A) RHEOMETRICS FLUIDS RHEOMETER DATA

FREQUENCY (1/sec)	G'' (dyne/cm**2)	STANDARD DEVIATION	G' (cyne/cm**2)	STANDARD DEVIATION
10.00	22.26	0.32	4.474	0.184
15.59	27.08	0.38	6.080	0.238
15.85	32.81	0.44	8.218	0.290
19.95	39.50	0.56	10.96	0.37
25.12	47.16	0.77	14.49	0.50
31.63	56.31	0.82	18.89	0.64
39.81	66.90	0.99	24.44	0.83
50.12	78.95	1.18	31.35	1.05
63.10	92.82	1.36	40.16	1.35
79.44	108.8	1.6	51.04	1.74
100.0	127.2	1.9	64.92	2.21
125.9	148.5	2.1	82.75	2.74
158.4	173.8	2.3	106.6	3.4
199.6	203.7	2.5	140.1	4.0
251.2	239.2	0.6	185.5	0.8

TABLE XXXIX

FREQUENCY, LOSS MODULUS(G'') AND STORAGE MODULUS(G') FOR A 36.3 g/L SOLUTION OF K125/DPM (SOLUTION 36A) RHEOMETRICS FLUIDS RHEOMETER DATA

FREQUENCY (1/sec)	G'' (dyne/cm**2)	STANDARD DEVIATION	G' (dyne/cm**2)	STANDARD DEVIATION
5.000	24.07	0.88	5.008	0.184
6.295	29.04	0.81	7.001	0.175
7.925	35.12	1.23	9.225	0.331
9.977	42.21	1.49	12.29	0.47
12.56	50.23	1.73	16.05	0.64
15.81	59.59	2.06	20.81	0.85
19.91	70.24	2.47	26.72	1.09
25.06	82.36	2.86	33.89	1.40
31.55	96.14	3.37	42.58	1.76
39.72	111.7	3.8	52.94	2.20
50.01	129.4	4.4	65.21	2.71
62.96	149.1	5.0	80.13	3.27
79.26	171.6	5.7	96.42	4.28
99.78	197.5	6.5	119.3	4.8
125.6	226.8	7.3	144.9	5.6
158.2	262.3	8.4	177.6	6.9
199.1	305.2	9.7	221.3	8.5

TABLE XL

FREQUENCY, LOSS MODULUS(G'') AND STORAGE MODULUS(G') FOR A 40.0 g/L SOLUTION OF K125/DPM (SOLUTION 40A) RHEOMETRICS FLUIDS RHEOMETER DATA

FREQUENCY (1/sec)	G'' (dyne/cm**2)	STANDARD DEVIATION	G' (dyne/cm**2)	STANDARD DEVIATION
2.500	24.64	0.75	5.852	0.626
3.147	29.67	0.76	7.698	0.909
3.962	36.15	1.05	10.38	0.82
4.988	43.37	1.39	13.68	0.89
6.230	51.37	1.66	17.97	1.03
7.906	60.95	1.68	23.13	1.15
9.953	71.64	1.91	29.45	1.46
12.53	83.67	2.07	37.13	1.57
15.78	97.21	2.28	46.42	1.74
19.86	112.3	2.5	57.41	1.90
25.00	129.2	2.8	70.25	1.98
31.48	147.9	2.9	85.23	2.04
39.63	168.6	3.2	102.7	2.2
49.89	192.2	3.7	123.0	2.2
62.81	217.7	4.0	145.9	2.1
79.07	246.4	4.4	172.6	2.1
99.55	279.0	4.9	203.8	1.8
125.3	316.5	5.4	240.2	1.5

TABLE XLI

FREQUENCY, LOSS MODULUS(G'') AND STORAGE MODULUS(G') FOR A 45.0 g/L SOLUTION OF K125/DPM (SOLUTION 45A) RHEOMETRICS FLUIDS RHEOMETER DATA

FREQUENCY (1/sec)	G'' (dyne/cm**2)	STANDARD DEVIATION	G' (dyne/cm**2)	STANDARD DEVIATION
5.000	69.72	0.13	28.17	0.57
6.295	81.47	0.28	35.80	0.57
7.925	94.56	0.04	44.68	0.71
9.977	109.4	-	55.57	0.86
12.56	125.4	0.1	68.05	0.92
15.81	143.1	-	82.75	1.15
19.91	162.8	0.1	99.81	1.40
25.06	184.2	0.3	119.2	1.6
31.55	207.6	0.2	141.4	1.9
39.72	233.2	0.3	166.5	2.1
50.01	261.7	0.6	194.8	2.5
62.96	292.7	0.7	226.8	2.6
79.26	327.4	0.6	262.9	3.0
99.78	366.9	0.7	304.3	3.4
125.6	411.1	0.8	350.6	3.5

TABLE XLII

FREQUENCY, LOSS MODULUS(G'') AND STORAGE MODULUS(G') FOR A 50.0 g/L SOLUTION OF K125/DPM (SOLUTION 50A) RHEOMETRICS FLUIDS RHEOMETER DATA

FREQUENCY (1/sec)	G'' (dyne/cm**2)	STANDARD DEVIATION	G' (dyne/cm**2)	STANDARD DEVIATION
1.581	49.07	0.27	16.05	0.14
1.991	58.52	0.43	20.98	0.18
2.506	68.98	0.34	27.25	0.15
3.155	79.89	0.29	34.89	0.36
3.978	93.68	0.46	44.15	0.37
5.001	108.4	0.65	55.26	0.48
6.295	123.5	0.81	68.47	1.06
7.926	141.6	0.40	83.13	0.92
9.978	161.0	0.42	101.0	1.2
12.56	181.4	0.38	120.7	1.6
15.82	204.0	0.46	143.6	1.9
19.91	228.5	0.53	169.6	2.3
25.07	254.9	0.67	198.7	2.8
31.56	283.5	0.59	231.3	3.4
39.73	314.4	0.60	267.3	4.1
50.01	348.2	0.82	307.5	4.9

TABLE XLIII

FREQUENCY, LOSS MODULUS(G'') AND STORAGE MODULUS(G') FOR A 20.0 g/L SOLUTION OF K125/DPM (SOLUTION 20B) RHEOMETRICS FLUIDS RHEOMETER DATA

FREQUENCY (1/sec)	G'' (dyne/cm**2)	STANDARD DEVIATION	G' (dyne/cm**2)	STANDARD DEVIATION
25.00	14.41	0.12	2.539	0.070
31.47	17.82	0.16	3.531	0.131
39.62	21.99	0.19	4.936	0.142
49.88	27.11	0.21	6.976	0.173
62.80	32.99	0.27	9.866	0.205
79.06	39.97	0.32	13.96	0.24
99.54	48.20	0.38	19.87	0.31
125.3	57.50	0.50	28.40	0.41
157.8	67.98	0.73	40.94	0.55
198.6	77.98	1.01	59.50	0.66
250.0	86.81	1.69	85.95	0.32

TABLE XLIV

FREQUENCY, LOSS MODULUS(G'') AND STORAGE MODULUS(G') FOR A 25.0 g/L SOLUTION OF K125/DPM (SOLUTION 25B) RHEOMETRICS FLUIDS RHEOMETER DATA

FREQUENCY (1/sec)	G'' (dyne/cm**2)	STANDARD DEVIATION	G' (dyne/cm**2)	STANDARD DEVIATION
10.00	11.31	0.09	1.587	0.099
12.59	14.60	0.06	2.223	0.071
15.85	18.04	0.06	3.096	0.048
19.95	22.12	0.04	4.266	0.050
25.12	27.02	0.07	5.823	0.092
31.63	32.81	0.08	7.947	0.072
39.81	39.74	0.18	10.73	0.06
50.12	47.92	0.21	14.42	0.02
63.10	57.47	0.26	19.49	0.09
79.44	68.66	0.33	26.15	0.21
100.0	81.74	0.43	35.17	0.29
125.9	96.90	0.54	47.46	0.62
158.5	114.8	0.8	64.92	1.15
199.6	134.7	1.4	90.43	2.02

TABLE XLV

FREQUENCY, LOSS MODULUS(G'') AND STORAGE MODULUS(G') FOR A 30.0 g/L SOLUTION OF K125/DPM (SOLUTION 309) RHEOMETRICS FLUIDS RHEOMETER DATA

FREQUENCY (1/sec)	G'' (dyne/cm**2)	STANDARD DEVIATION	G' (dyne/cm**2)	STANDARD DEVIATION
10.00	22.57	0.28	4.485	0.245
12.59	27.45	0.34	6.087	0.279
15.86	33.30	0.43	8.248	0.395
19.95	40.15	0.51	10.99	0.47
25.12	48.12	0.63	14.53	0.59
31.63	57.36	0.71	18.99	0.75
39.81	68.12	0.79	24.59	0.93
50.12	80.52	0.95	31.49	1.09
63.10	94.72	1.08	40.39	1.38
79.44	111.2	1.3	51.38	1.72
100.0	130.1	1.4	65.32	2.12
125.9	152.0	1.5	83.22	2.49
158.5	178.4	1.7	107.0	2.7

TABLE XLVI

FREQUENCY, LOSS MODULUS(G'') AND STORAGE MODULUS(G') FOR A 36.3 g/L SOLUTION OF K125/DPM (SOLUTION 36B) RHEOMETRICS FLUIDS RHEOMETER DATA

FREQUENCY (1/sec)	G'' (dyne/cm**2)	STANDARD DEVIATION	G' (dyne/cm**2)	STANDARD DEVIATION
5.000	27.11	0.70	6.281	0.363
6.295	32.90	1.09	8.397	0.132
7.925	39.42	0.86	11.24	0.38
9.977	47.21	1.03	14.89	0.46
12.56	55.91	1.16	19.31	0.54
15.81	66.01	1.36	24.85	0.69
19.91	77.53	1.59	31.65	0.80
25.06	90.62	1.79	39.80	0.98
31.55	105.0	1.8	49.62	1.07
39.72	121.7	2.3	61.22	1.27
50.01	140.4	2.5	74.88	1.53
62.96	161.1	2.9	91.17	1.75
79.26	184.9	3.2	110.4	2.0
99.78	212.3	3.7	133.7	2.3
125.6	243.1	4.2	161.0	2.8
158.2	280.6	4.9	195.2	3.3
199.1	325.9	5.8	240.1	4.1

TABLE XLVII

FREQUENCY, LOSS MODULUS(G'') AND STORAGE MODULUS(G') FOR A 40.0 g/L SOLUTION OF K125/DPM (SOLUTION 40B) RHEOMETRICS FLUIDS RHEOMETER DATA

FREQUENCY (1/sec)	G'' (dyne/cm**2)	STANDARD DEVIATION	G' (dyne/cm**2)	STANDARD DEVIATION
2.500	22.79	0.07	4.553	0.052
3.147	27.50	0.30	6.233	0.025
3.962	33.51	0.29	8.492	0.105
4.988	40.48	0.18	11.50	0.03
6.280	48.05	0.48	15.26	0.04
7.906	57.20	0.57	19.92	0.10
9.953	67.50	0.64	25.79	0.13
12.53	79.09	0.74	32.64	0.51
15.78	92.19	0.87	41.51	0.29
19.86	106.8	0.92	51.71	0.32
25.00	123.1	0.99	63.83	0.50
31.48	141.3	1.1	77.87	0.61
39.63	161.5	1.3	94.35	0.81
49.89	184.5	1.3	113.6	0.9
62.81	209.2	1.6	135.5	1.1
79.07	237.4	1.7	160.9	1.2
99.55	269.6	2.0	190.6	1.4
125.3	306.6	2.3	225.6	1.3
157.8	350.6	2.8	267.5	0.8
198.6	404.3	3.4	320.5	0.8

TABLE XLVIII

FREQUENCY, LOSS MODULUS(G'') AND STORAGE MODULUS(G') FOR A 50.0 g/L SOLUTION OF K125/DPM (SOLUTION 508) RHEOMETRICS FLUIDS RHEOMETER DATA

FREQUENCY (1/sec)	G'' (cyne/cm**2)	STANDARD DEVIATION	G' (cyne/cm**2)	STANDARD DEVIATION
1.000	35.14	0.81	3.561	0.459
1.259	42.27	1.06	11.72	0.69
1.585	50.61	1.26	15.45	0.71
1.995	59.75	0.79	20.59	1.12
2.512	70.79	1.55	26.82	1.15
3.160	82.81	1.70	34.76	1.79
3.981	96.38	1.86	44.01	1.96
5.012	111.4	2.2	55.17	2.12
6.310	127.6	1.6	68.77	2.74
7.944	145.8	2.4	84.04	2.90
10.00	165.5	2.7	102.2	3.36
12.59	186.5	2.8	122.5	3.6
15.85	209.6	3.0	145.9	3.9
19.96	234.5	3.2	172.3	4.3
25.12	261.3	3.3	201.9	4.6
31.63	290.5	3.7	235.0	5.0
39.82	322.0	4.1	271.6	5.2
50.13	356.3	4.5	312.1	5.5
63.11	393.7	5.1	356.9	5.9
79.45	435.4	5.7	406.6	6.2
100.0	482.5	6.2	462.1	6.7

TABLE XLIX

Parameters for the Equation $\eta' = a\omega^{b-1}$ for K125/DPM Solutions

Series A Solutions

Solution Designation	a	b	ω_o
20A	1.66	0.726	20.0
30A	5.21	0.693	6.4
36A	10.9	0.631	2.50
40A	21.4	0.560	1.80
45A	35.1	0.512	1.10
50A	54.2	0.478	0.450

TABLE L

Parameters for the Equation $\eta' = a\omega^{b-1}$ for K125/DPM Solutions

Series B Solutions

Solution Designation	a	b	ω_o
20B	2.10	0.681	17.0
25B	2.58	0.749	7.00
30B	5.32	0.694	6.00
36B	12.4	0.617	2.30
40B	19.2	0.575	1.65
50B	58.4	0.461	0.420

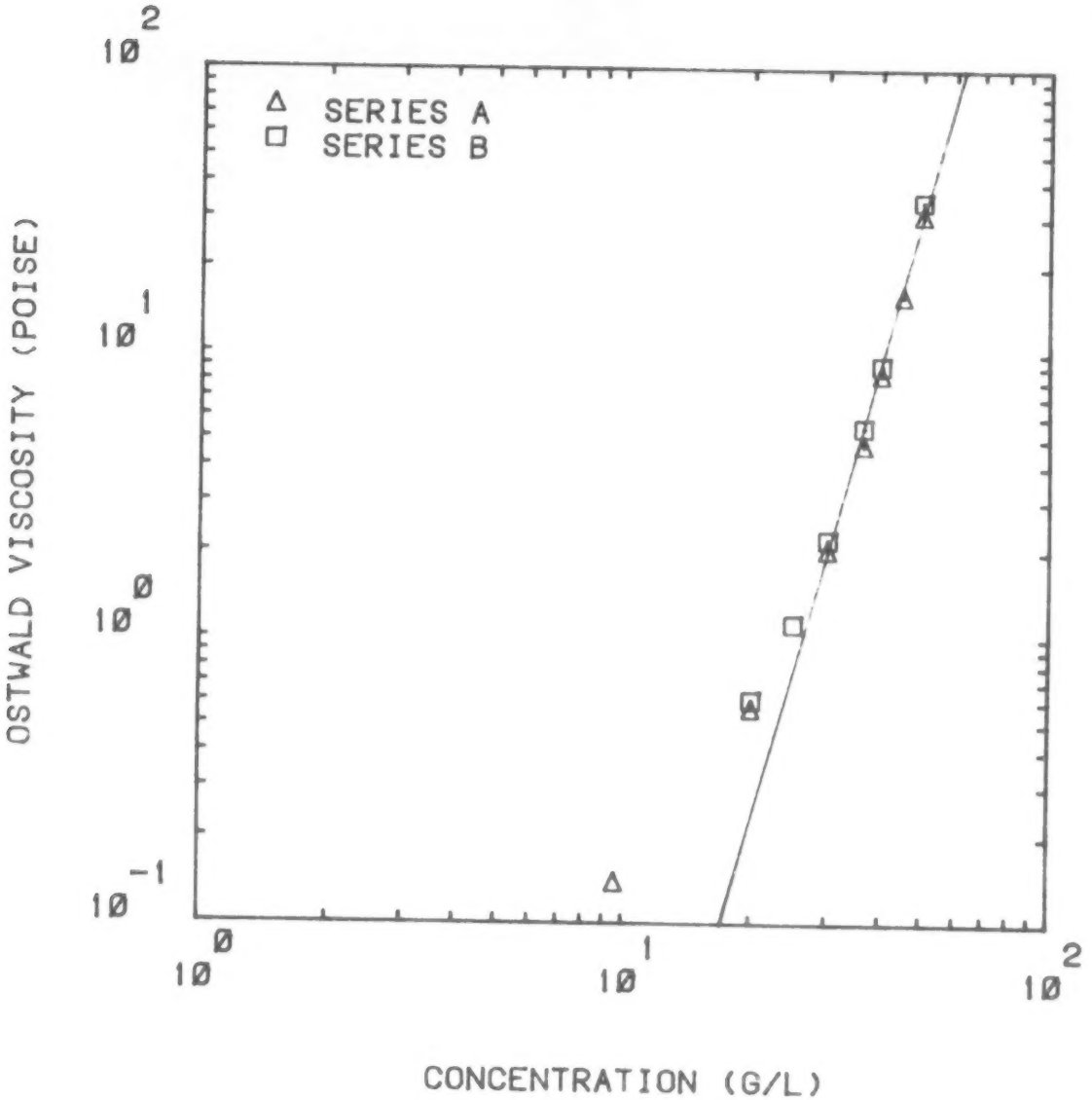


FIGURE 1 OSTWALD VISCOSITY AS A FUNCTION OF CONCENTRATION

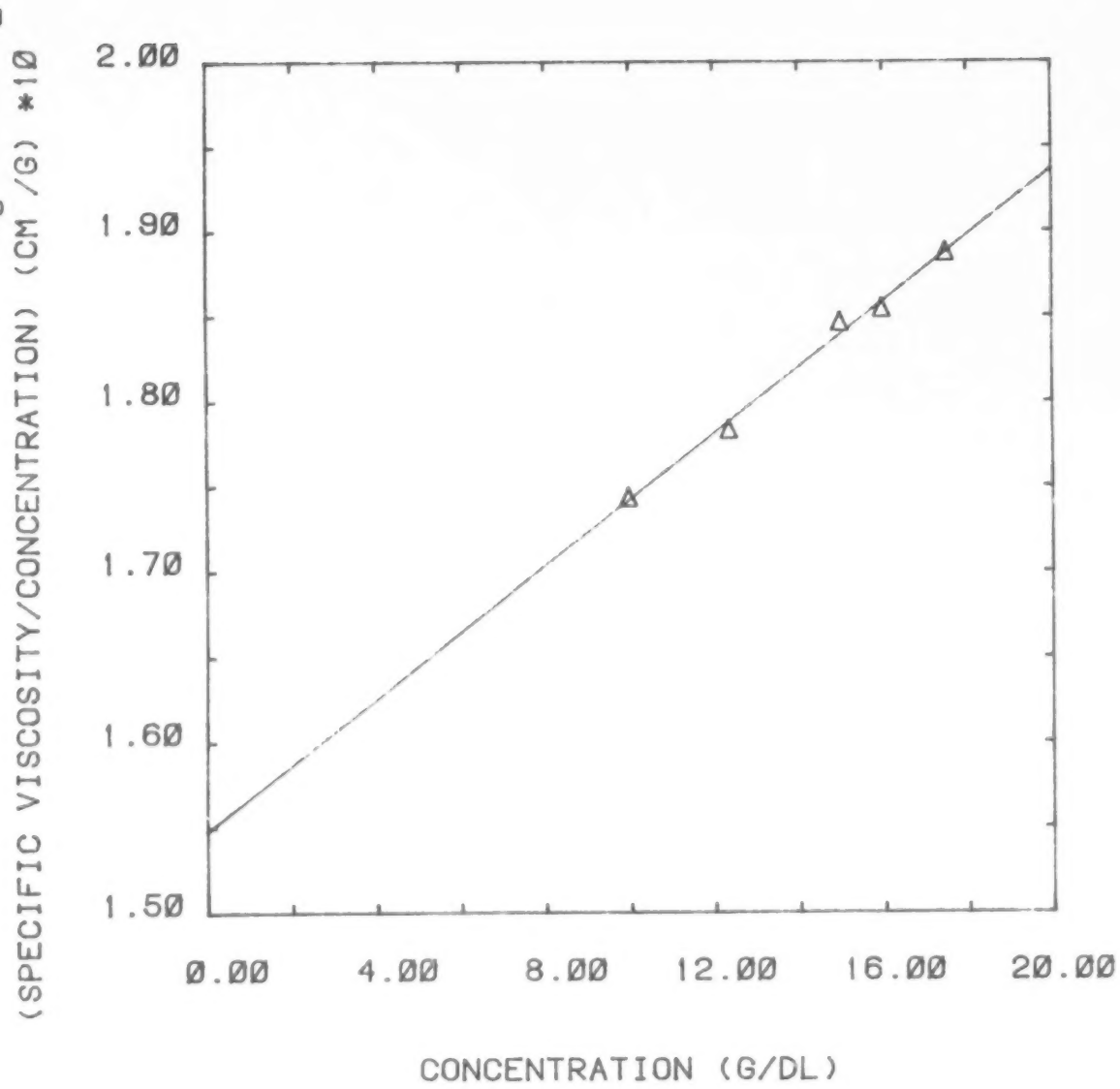


FIGURE 2 (SPECIFIC VISCOSITY/CONCENTRATION) AS A FUNCTION OF CONCENTRATION

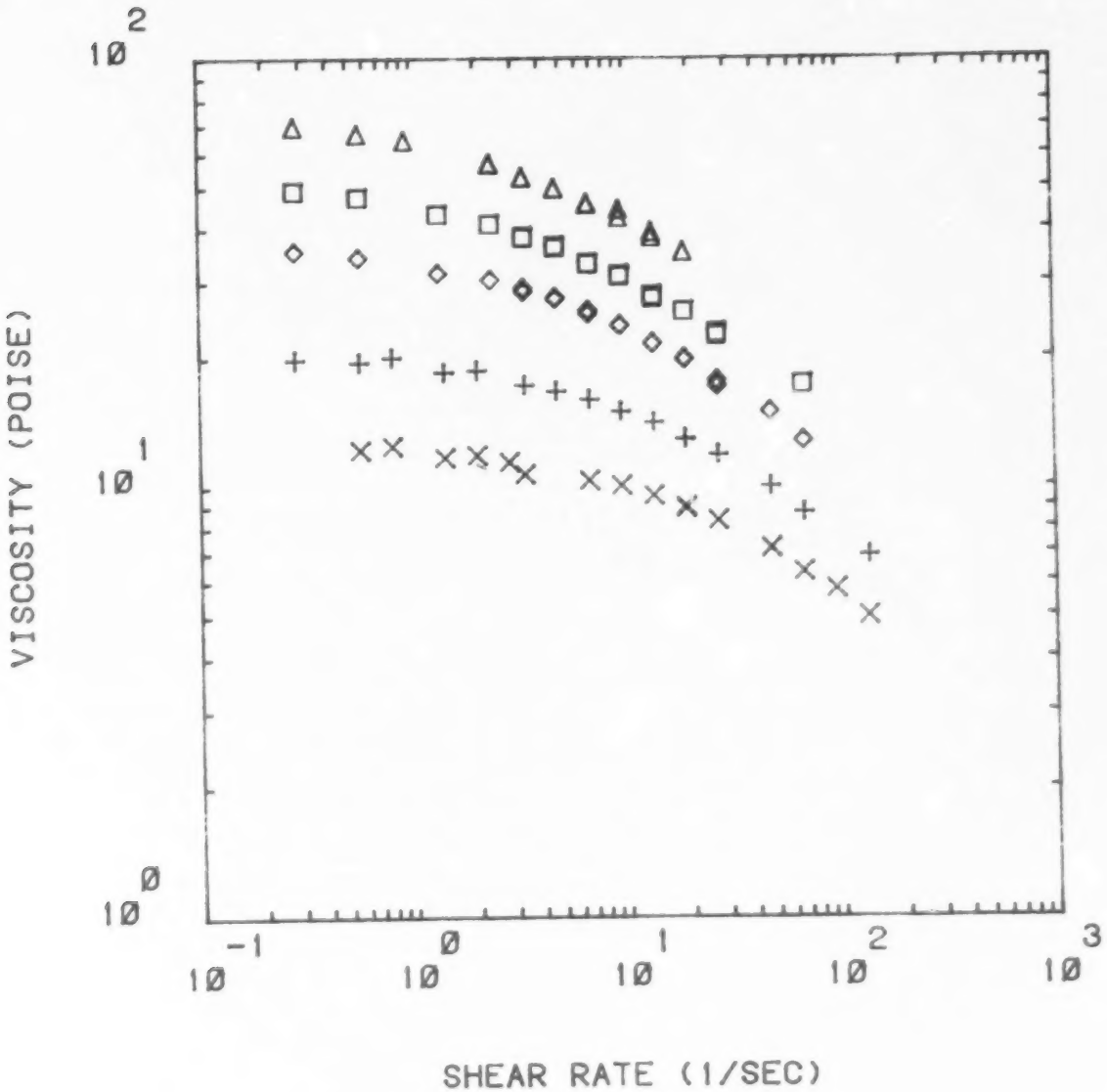


FIGURE 3 VISCOSITY AS A FUNCTION OF SHEAR RATE FOR A 50 G/L SOLUTION OF K125/DPM (SOLUTION 50A) AT TEMPERATURES △ 15C □ 20C ◇ 25C + 35C × 45C

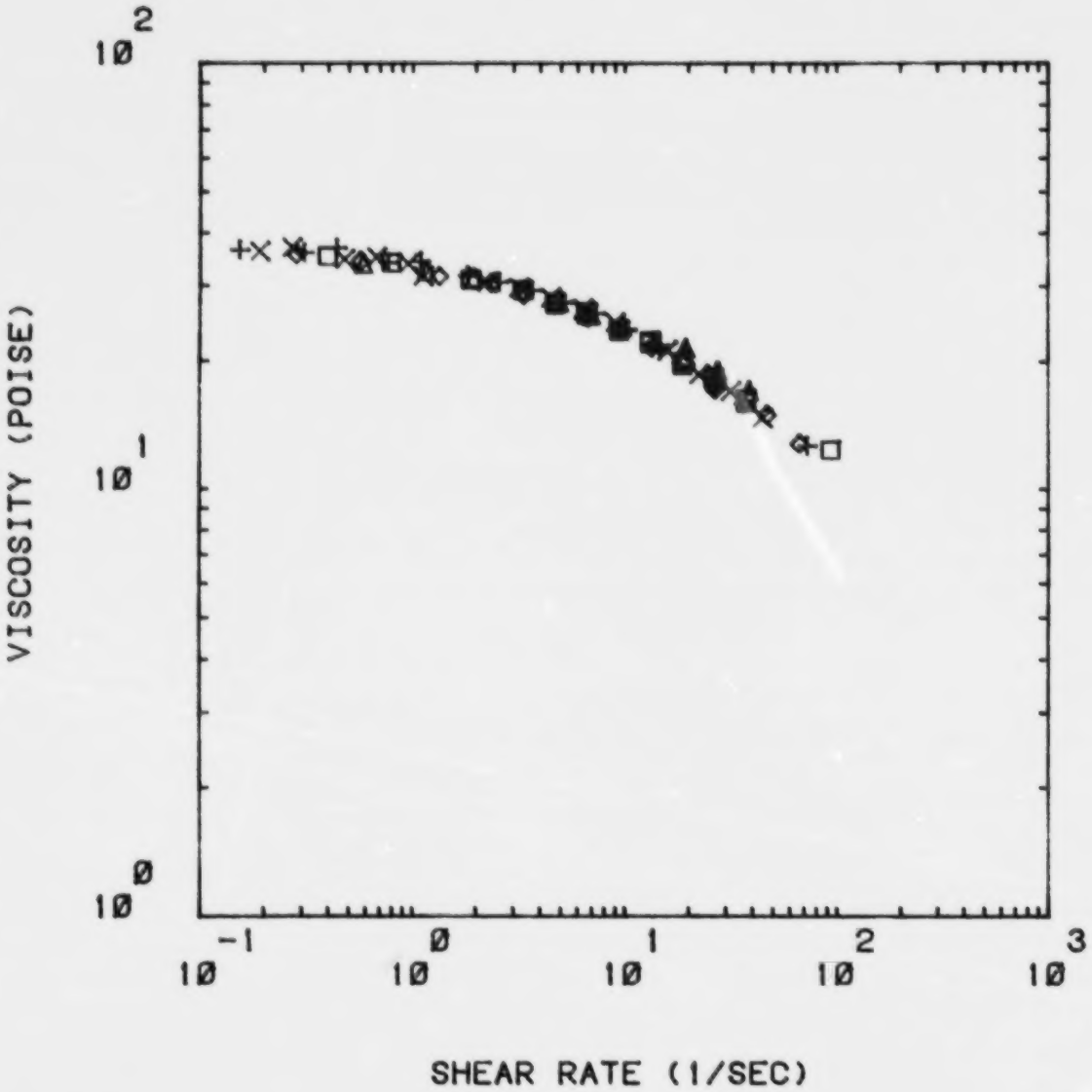


FIGURE 4 VISCOSITY AS A FUNCTION OF SHEAR RATE FOR A 50 G/L SOLUTION OF K125/DPM (SOLUTION 50A) ALL DATA REDUCED TO 25 C

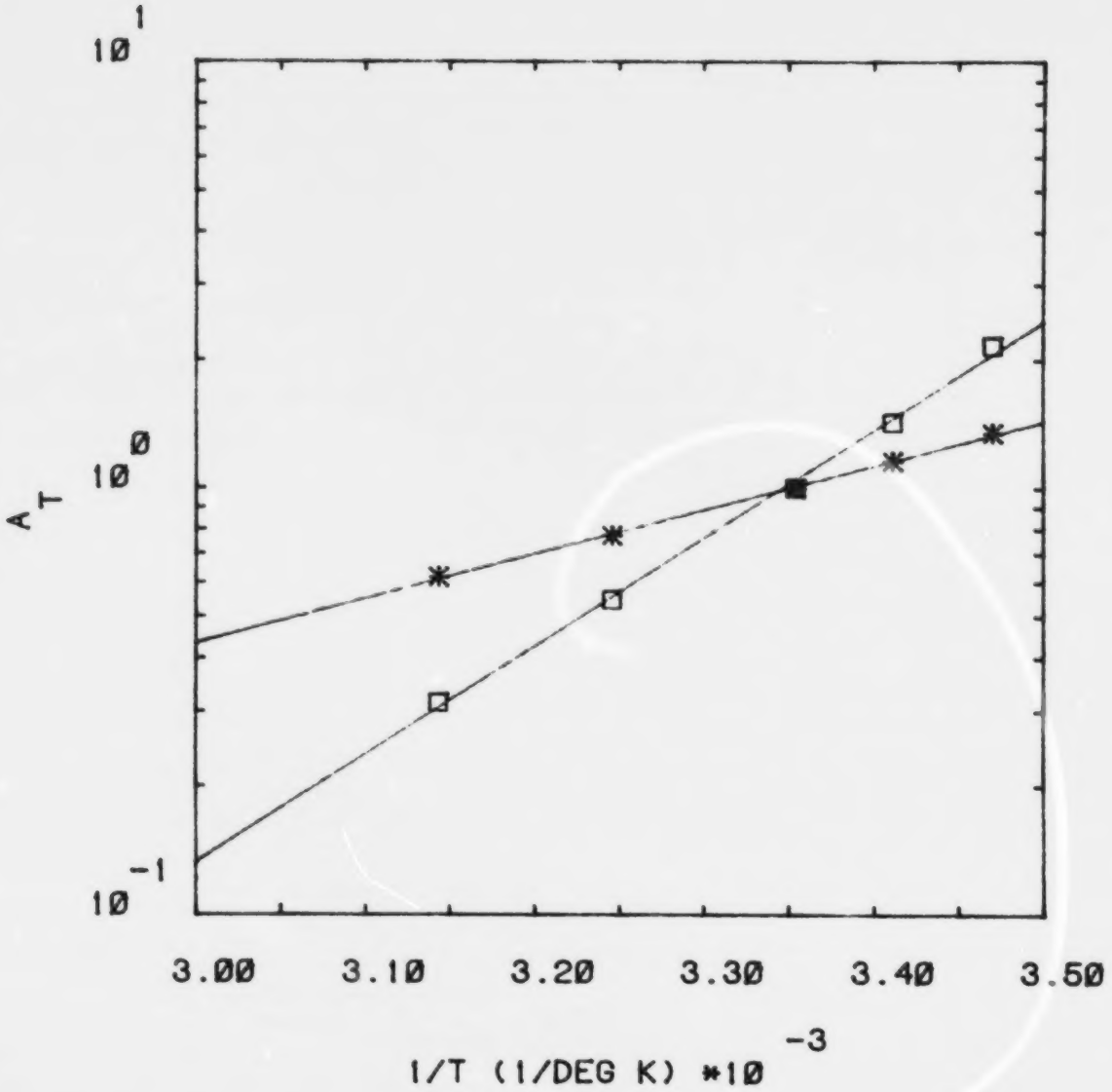


FIGURE 5 A_T AS A FUNCTION OF 1/T FOR A 20 G/L SOLUTION OF K125/DPM (SOLUTION 20A) * AND A 50 G/L SOLUTION OF K125/DPM (SOLUTION 50A) □ .

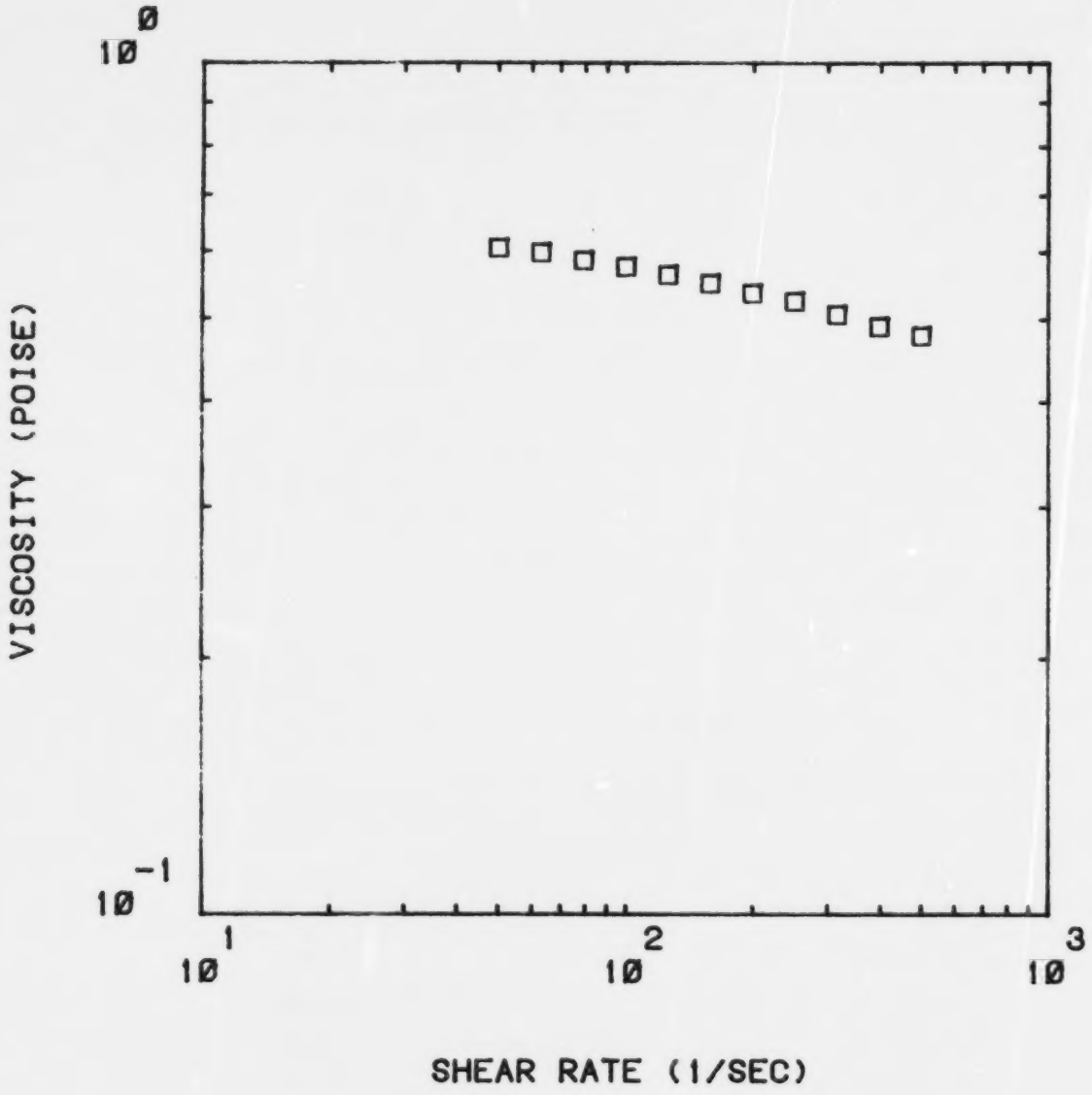


FIGURE 6 VISCOSITY AS A FUNCTION OF SHEAR RATE FOR A 20 G/L SOLUTION OF K125/DPM (SOLUTION 20A)

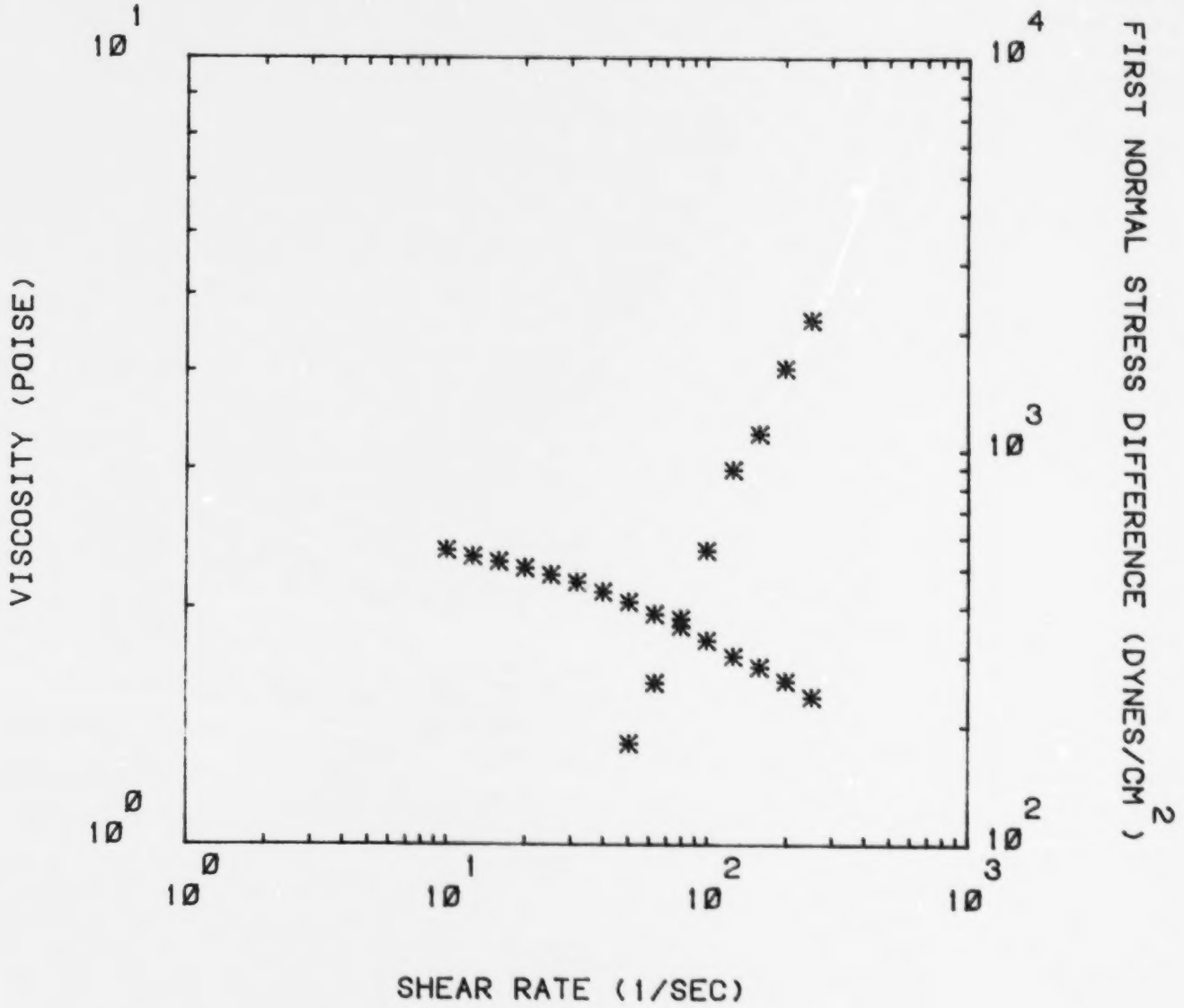


FIGURE 7 VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE AS A FUNCTION OF SHEAR RATE FOR A 30 G/L SOLUTION OF K125/DPM (SOLUTION 30A)

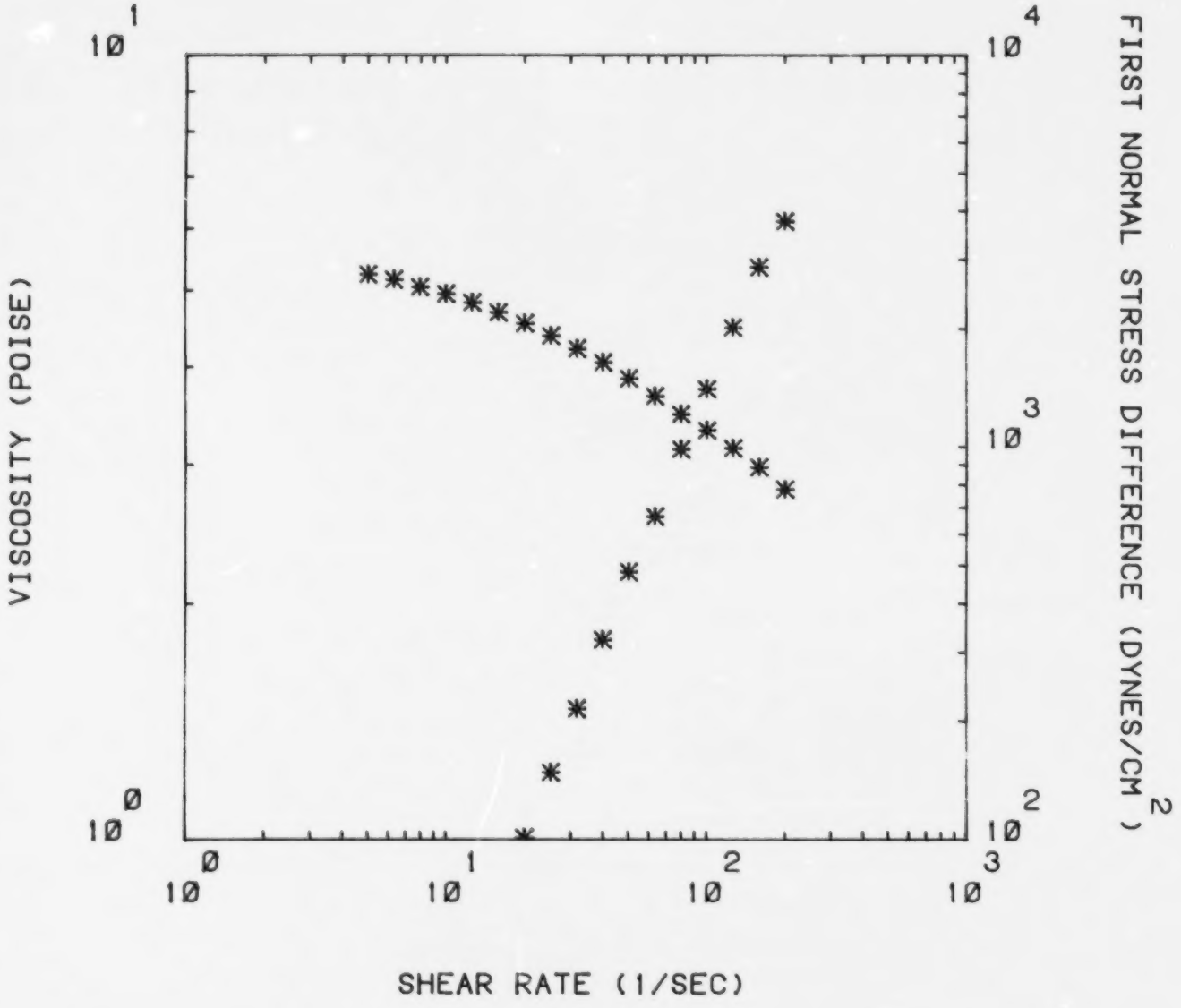


FIGURE 8 VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE AS A FUNCTION OF SHEAR RATE FOR A 36.3 G/L SOLUTION OF K125/DPM (SOLUTION 36A)

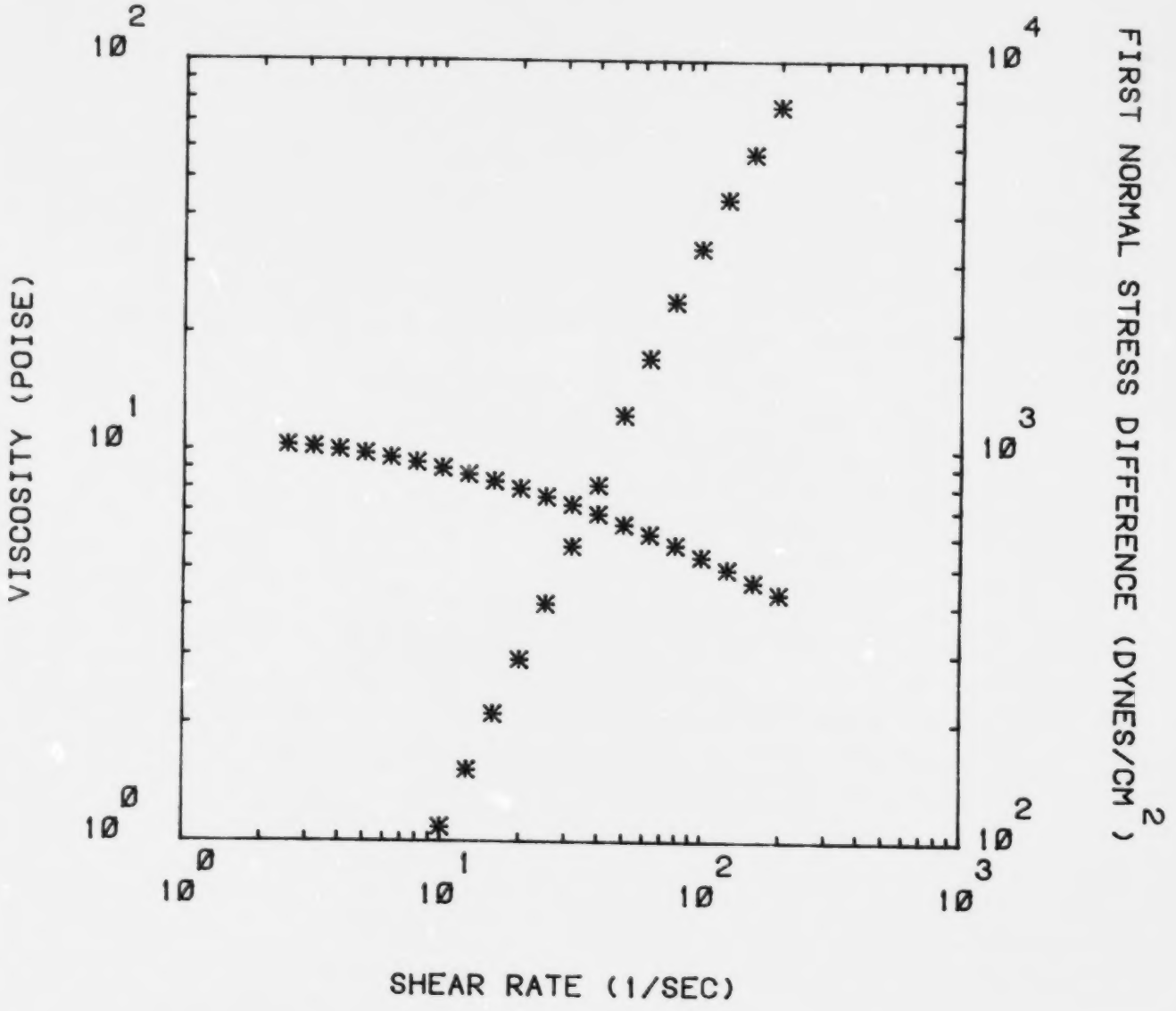


FIGURE 9 VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE AS A FUNCTION OF SHEAR RATE FOR A 40 G/L SOLUTION OF K125/DPM (SOLUTION 40A)

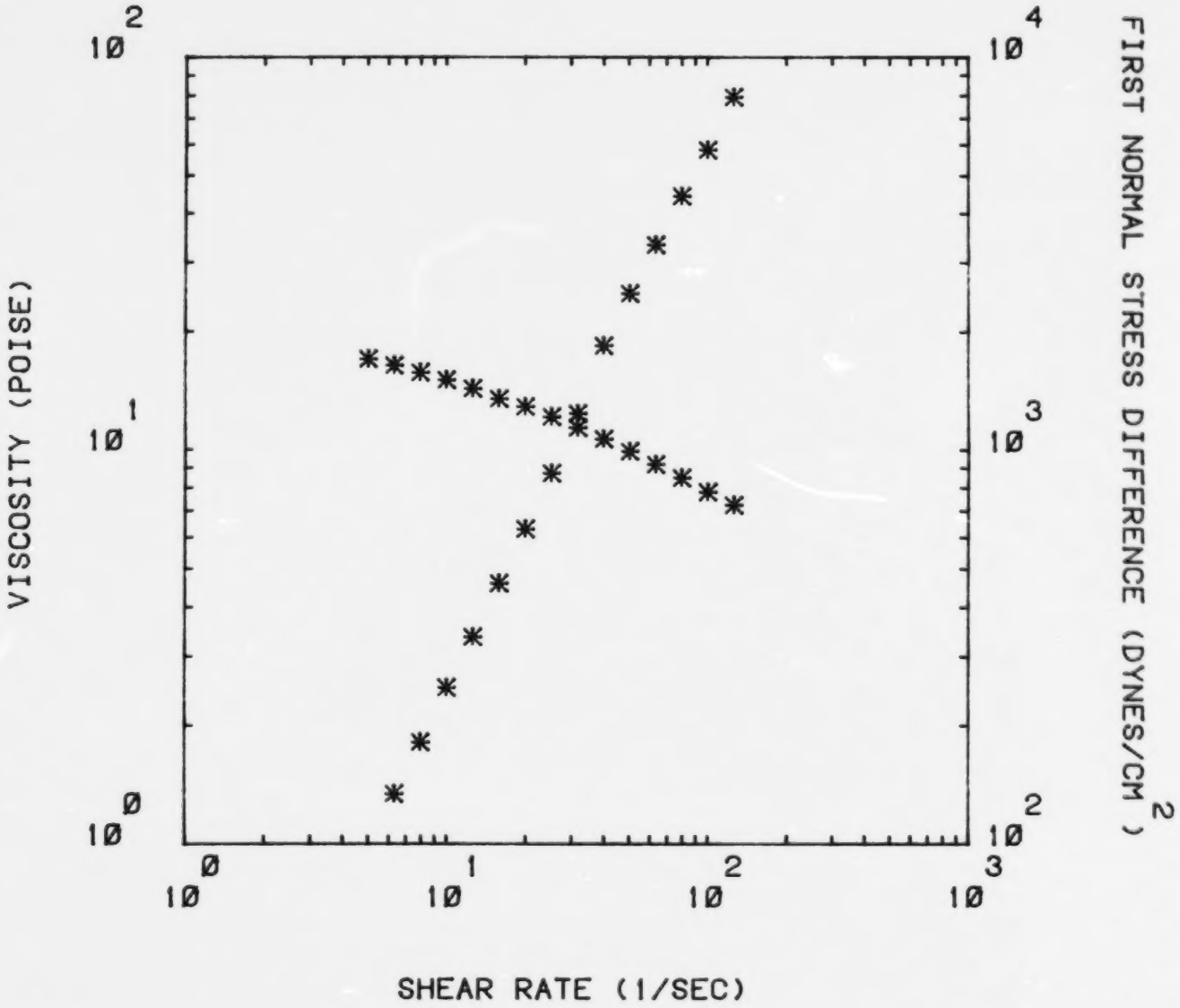


FIGURE 10 VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE AS A FUNCTION OF SHEAR RATE FOR A 45 G/L SOLUTION OF K125/DPM (SOLUTION 45A)

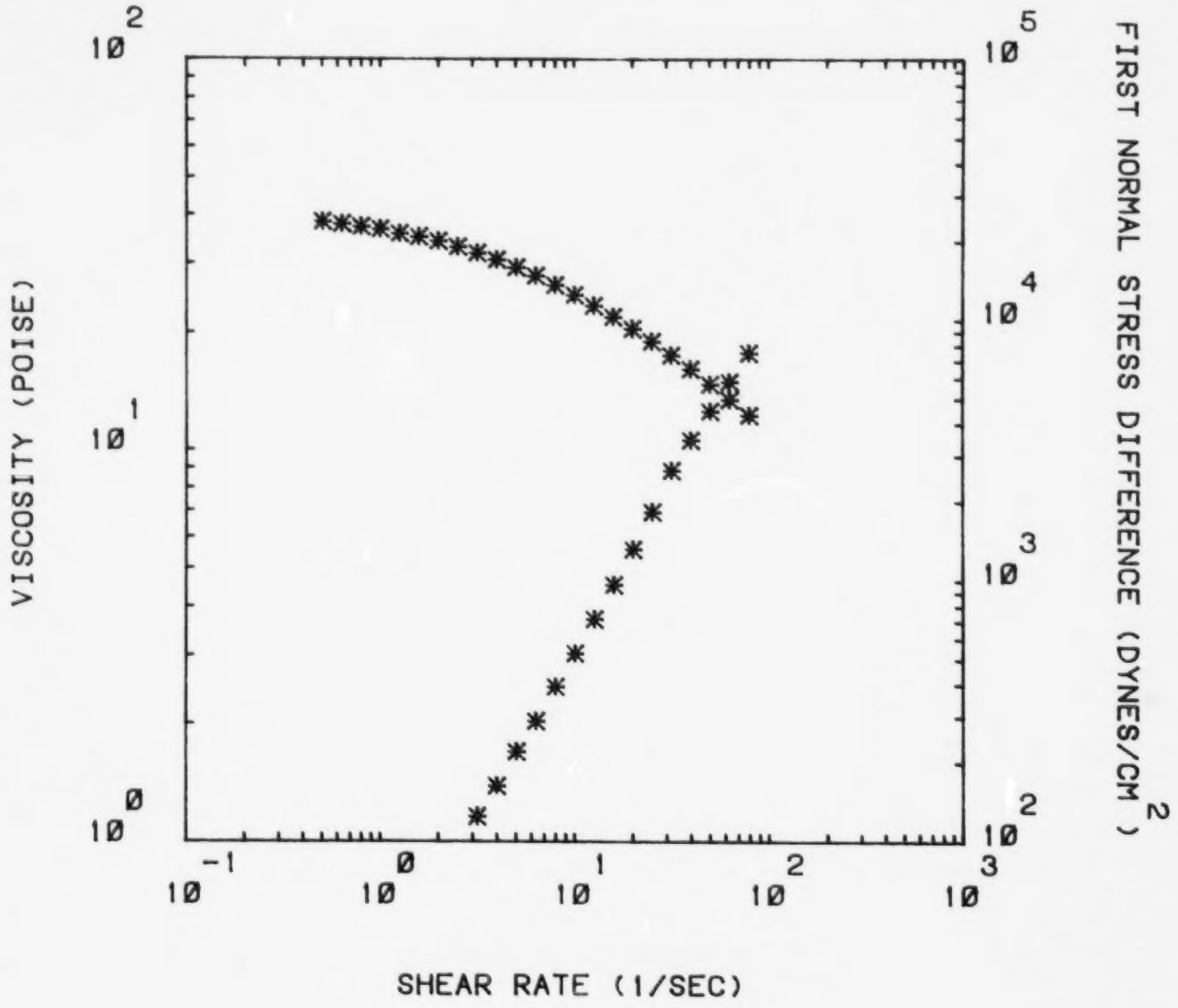


FIGURE 11 VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE AS A FUNCTION OF SHEAR RATE FOR A 50 G/L SOLUTION OF K125/DPM (SOLUTION 50A)

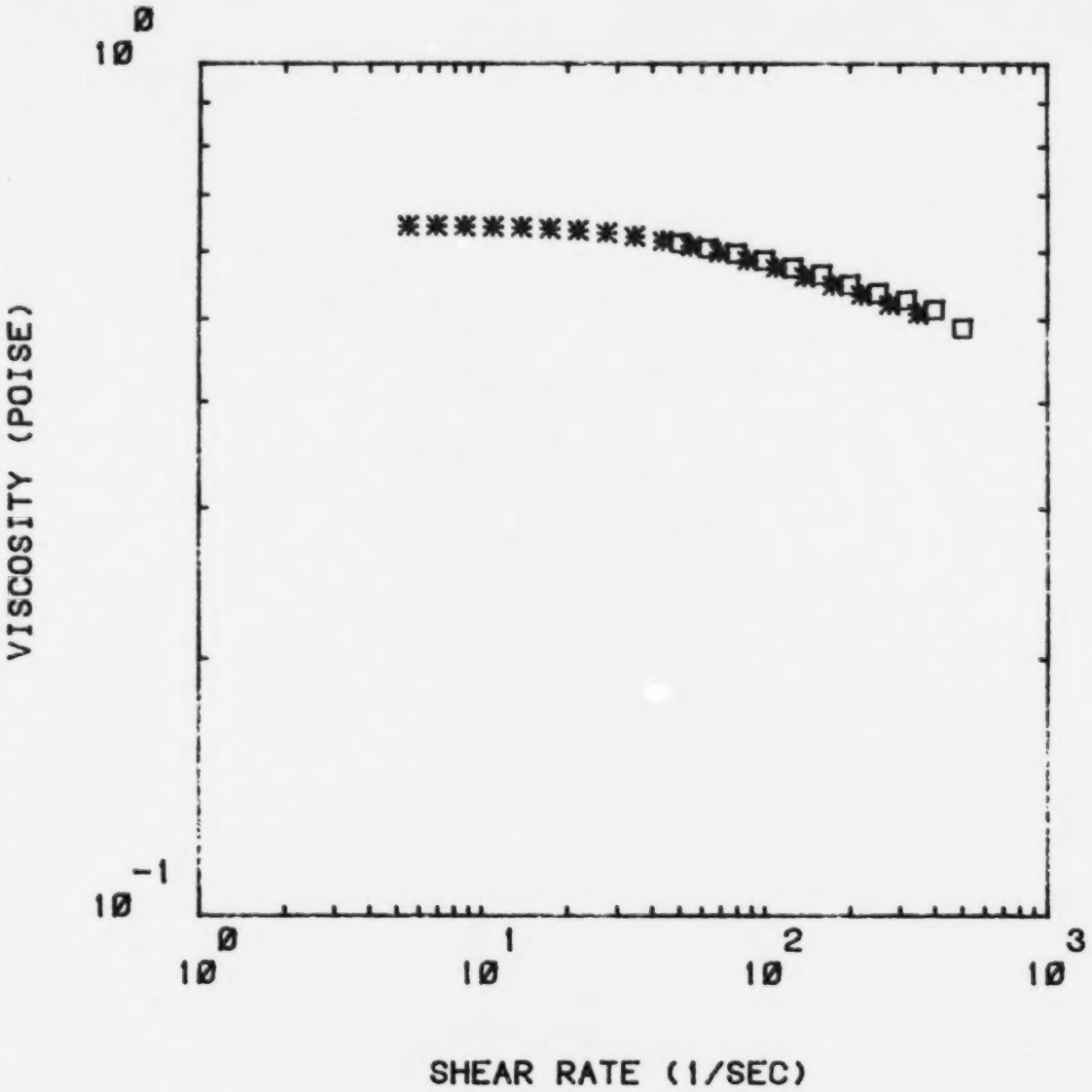


FIGURE 12 VISCOSITY AS A FUNCTION OF SHEAR RATE FOR A 20.0 G/L SOLUTION OF K125/DPM (SOLUTION 20B) □ RHEOMETRICS FLUIDS RHEOMETER * WEISSENBERG R17 RHEOGONIOMETER

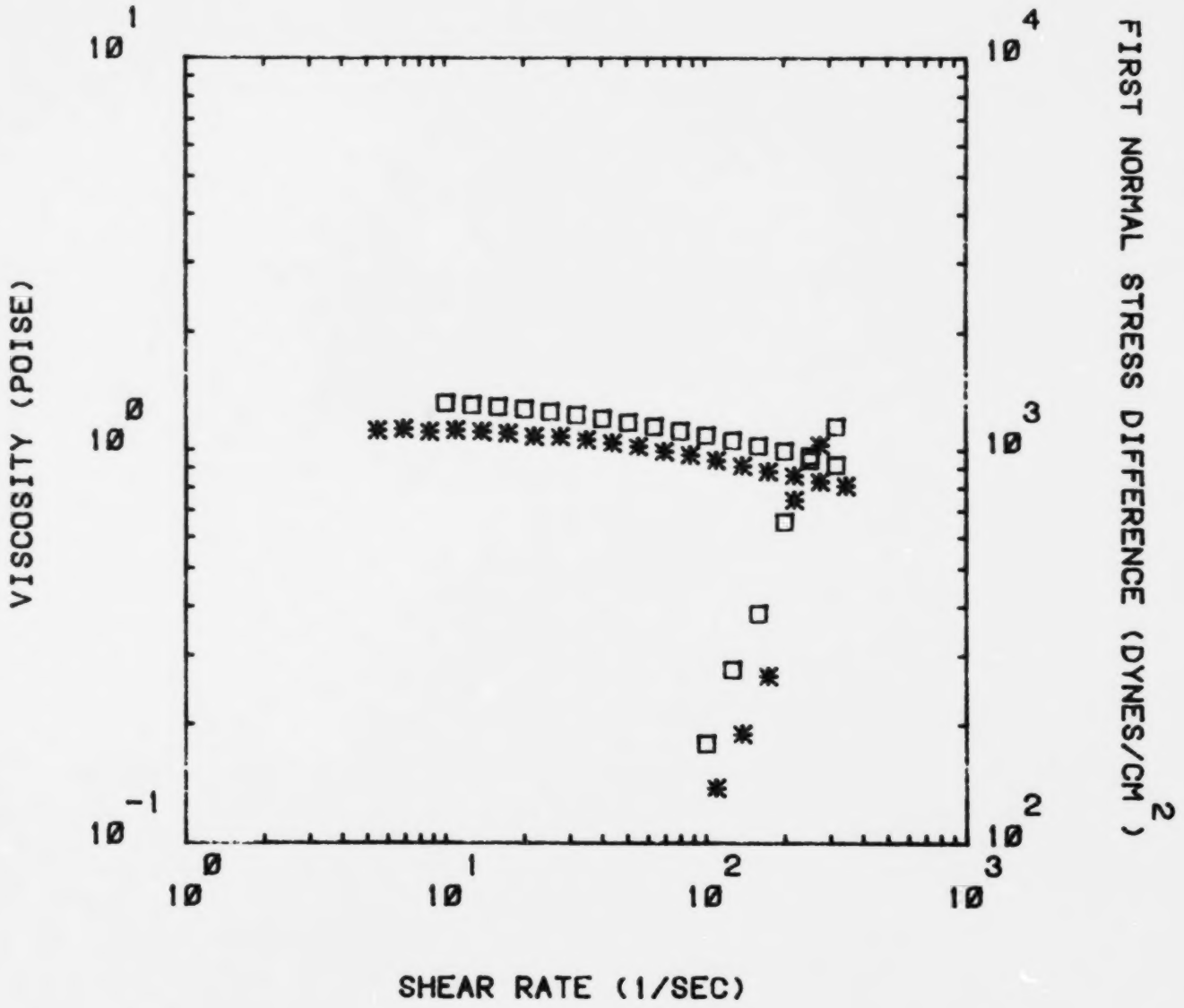


FIGURE 13 VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE AS A FUNCTION OF SHEAR RATE FOR A 25.0 G/L SOLUTION OF K125/DPM (SOLUTION 25B) □ RHEOMETRIC FLUIDS RHEOMETER * WEISSENBERG R17 RHEOGONIOMETER

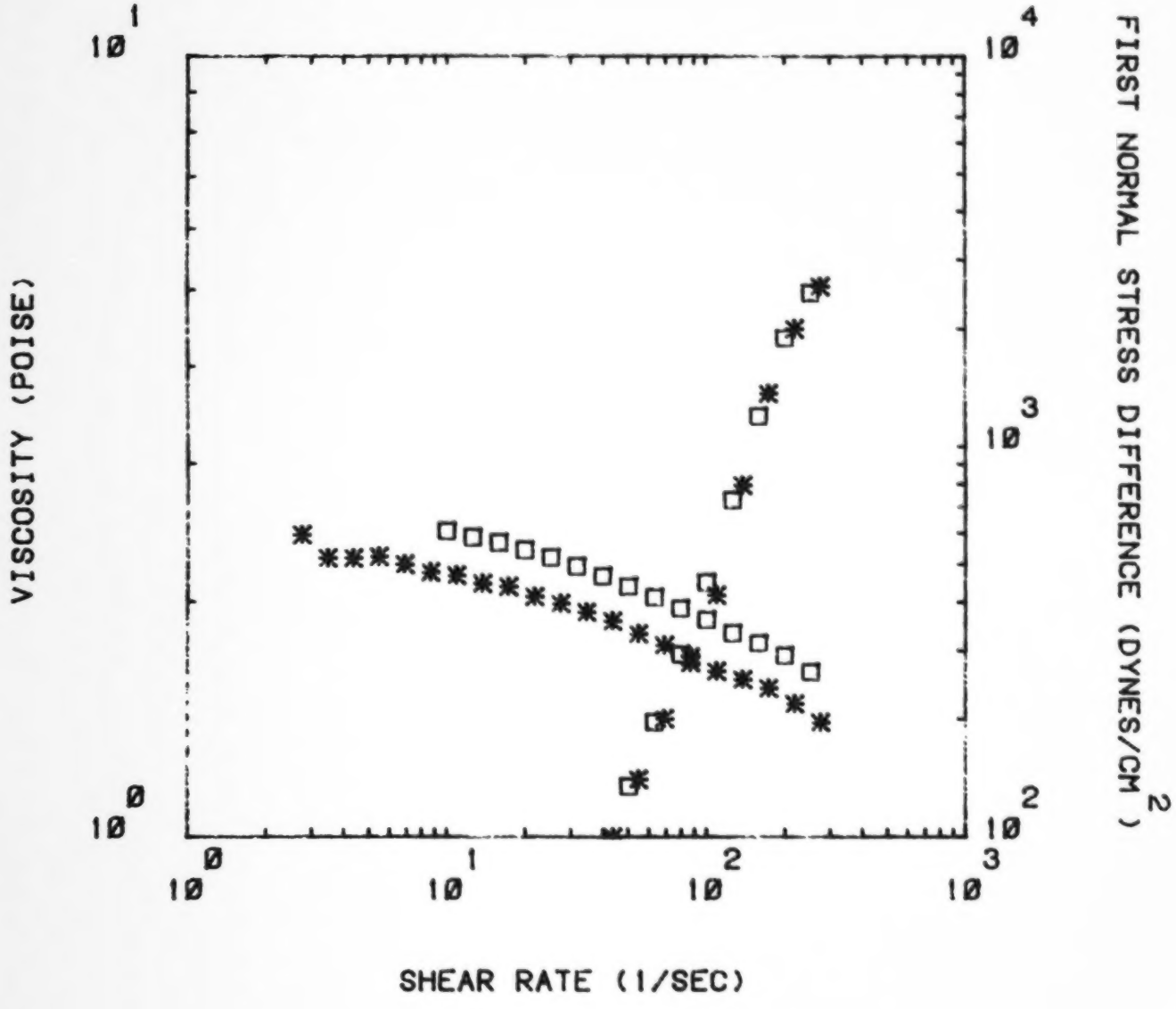


FIGURE 14 VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE AS A FUNCTION OF SHEAR RATE FOR A 30.0 G/L SOLUTION OF K125/DPM (SOLUTION 30B) □ RHEOMETRICS FLUIDS RHEOMETER * WEISSENBERG R17 RHEOGONIOMETER

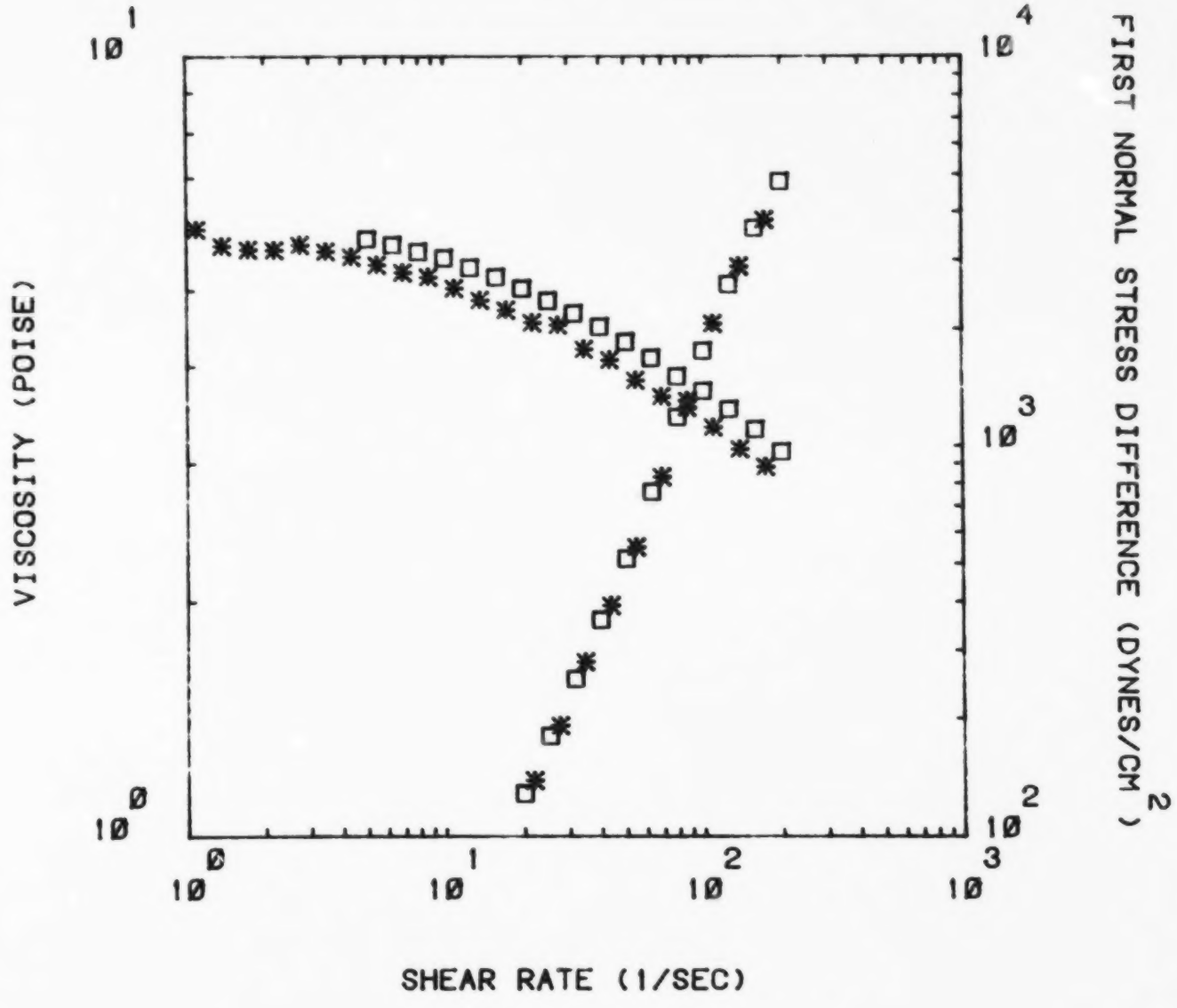


FIGURE 15 VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE AS A FUNCTION OF SHEAR RATE FOR A 36.3 G/L SOLUTION OF K125/DPM (SOLUTION 36B) □ RHEOMETRICS FLUIDS RHEOMETER ✱ WEISSENBERG R17 RHEOGONIOMETER

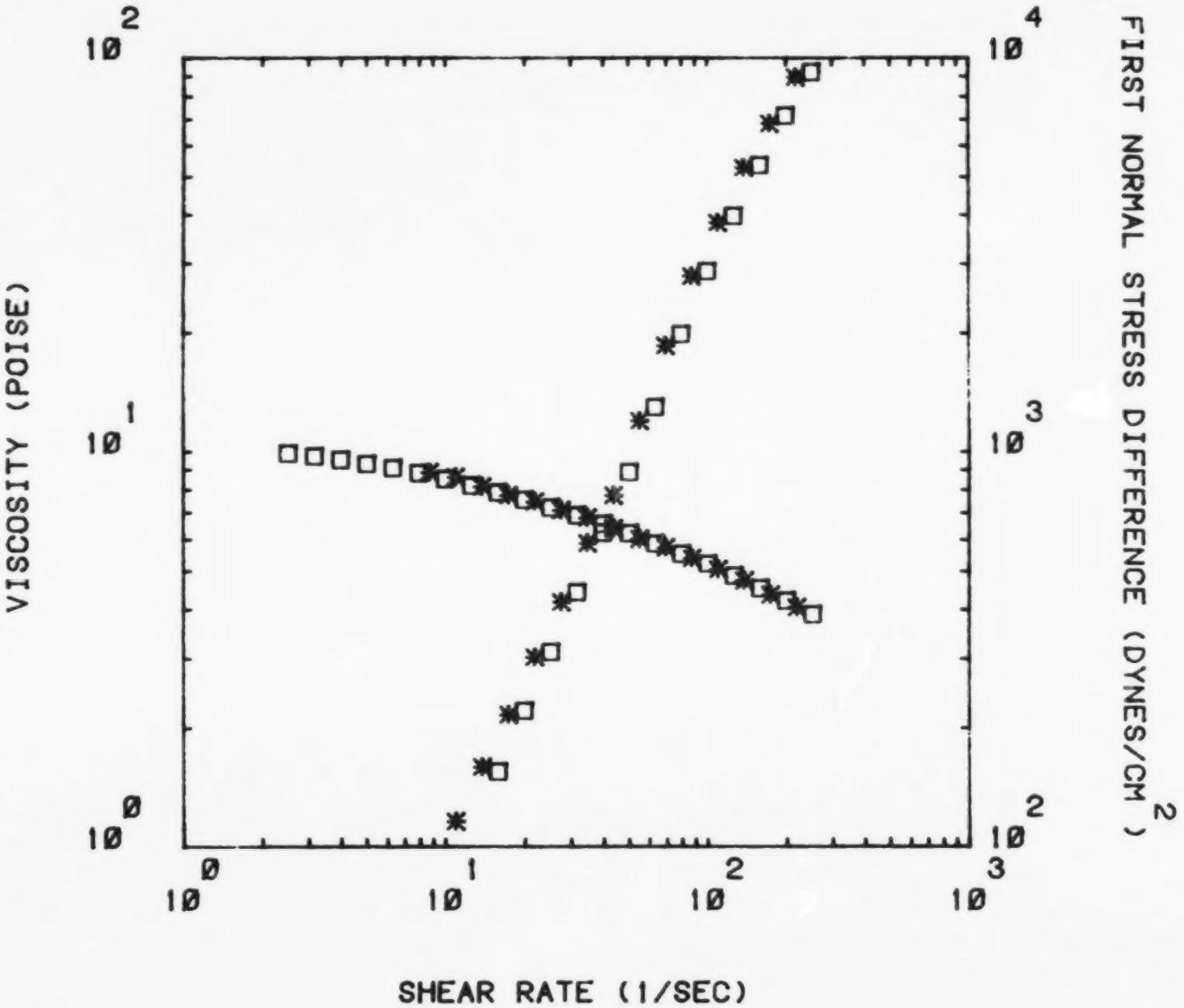


FIGURE 16 VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE AS A FUNCTION OF SHEAR RATE FOR A 40 G/L SOLUTION OF K125/DPM (SOLUTION 40B) □ RHEOMETRICS FLUIDS RHEOMETER * WEISSENBERG R17 RHEOGONIOMETER

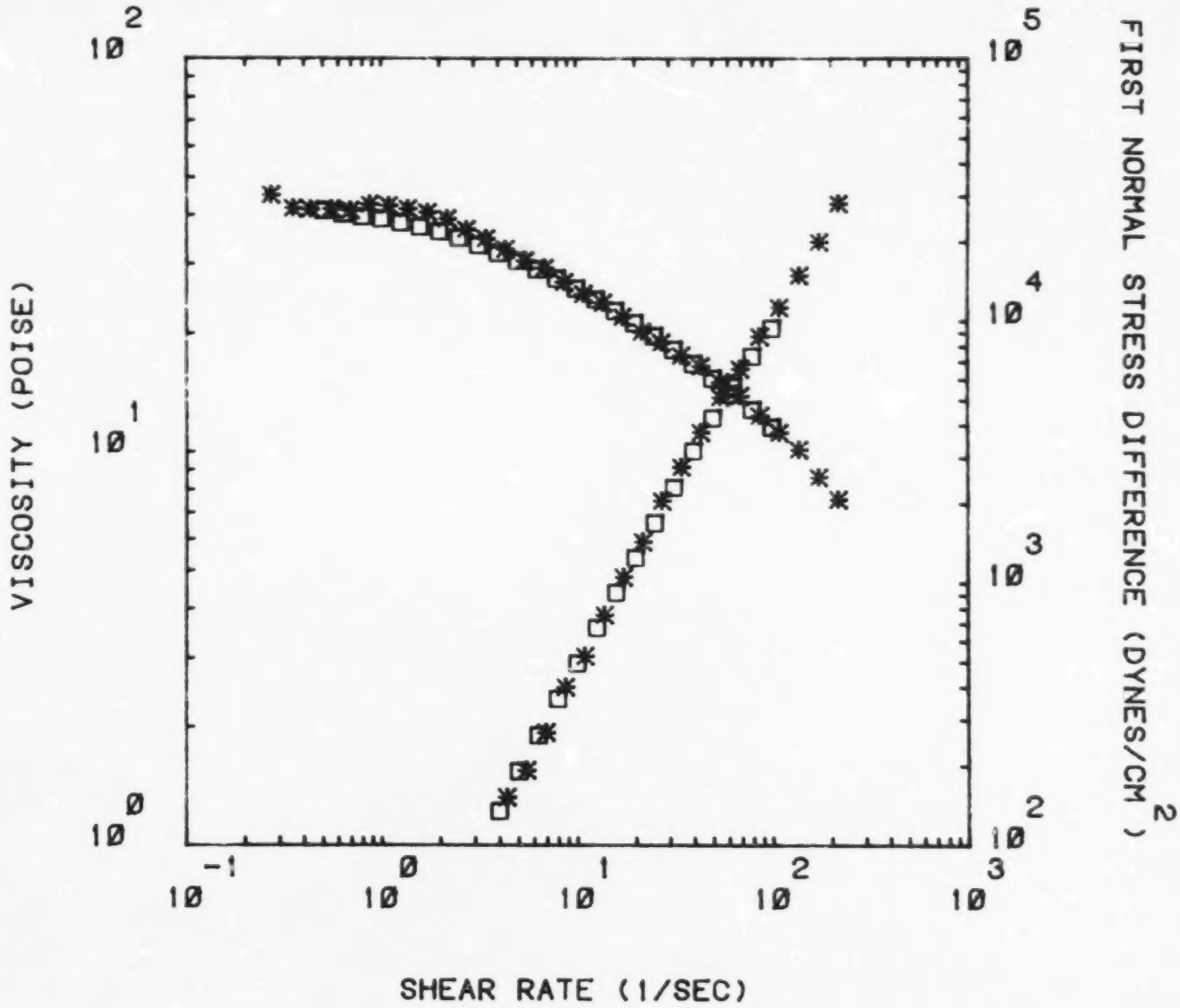


FIGURE 17 VISCOSITY AND FIRST NORMAL STRESS DIFFERENCE AS A FUNCTION OF SHEAR RATE FOR A 50 G/L SOLUTION OF K125/DPM (SOLUTION 50B) □ RHEOMETRICS FLUIDS RHEOMETER * WEISSENBERG R17 RHEOGONIOMETER

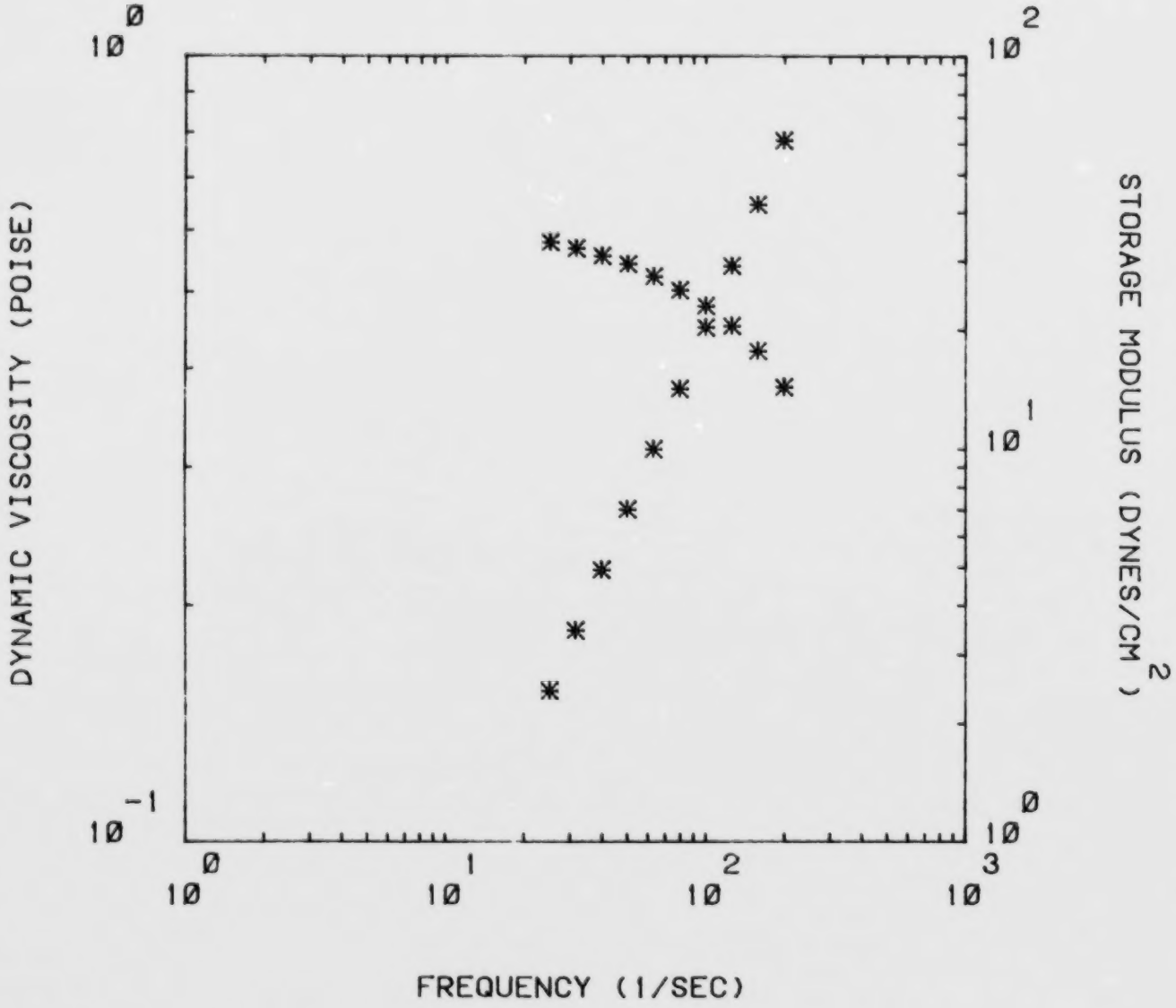


FIGURE 18 DYNAMIC VISCOSITY AND STORAGE MODULUS AS A FUNCTION OF FREQUENCY FOR A 20 G/L SOLUTION OF K125/DPM (SOLUTION 20A)

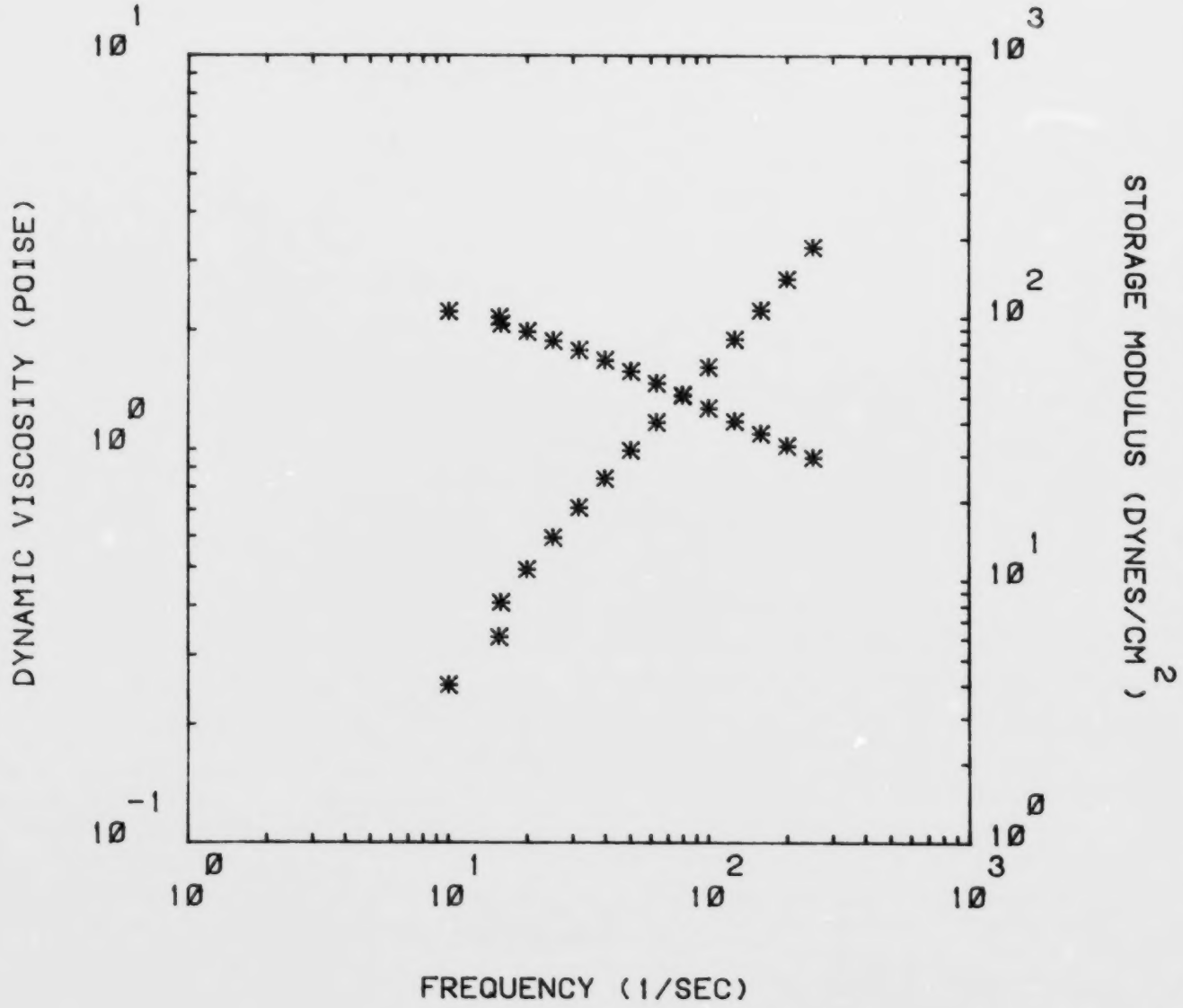


FIGURE 19 DYNAMIC VISCOSITY AND STORAGE MODULUS AS A FUNCTION OF FREQUENCY FOR A 30 G/L SOLUTION OF K125/DPM (SOLUTION 30A)

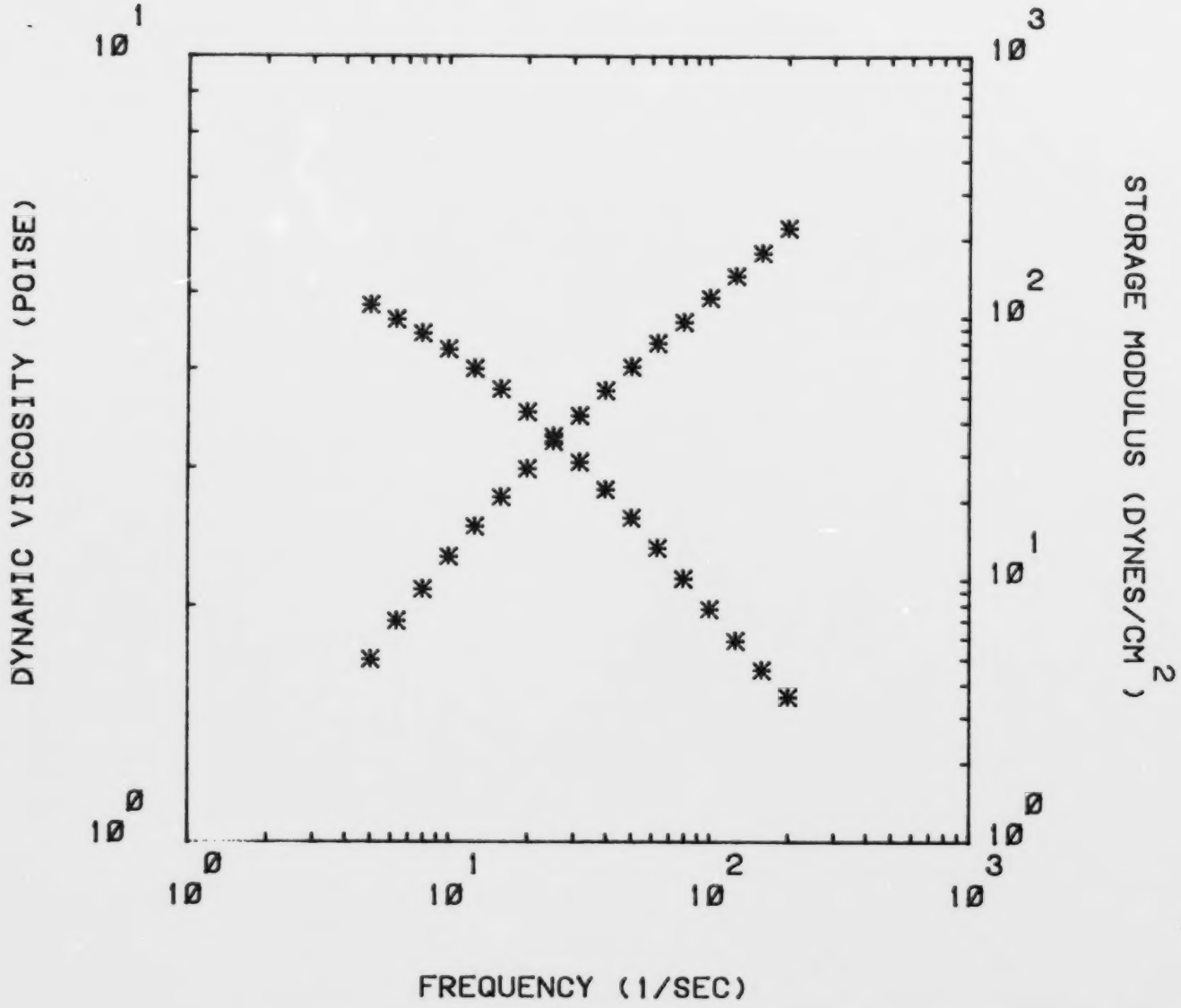


FIGURE 20 DYNAMIC VISCOSITY AND STORAGE MODULUS AS A FUNCTION OF FREQUENCY FOR A 36.3 G/L SOLUTION OF K125/DPM (SOLUTION 36A)

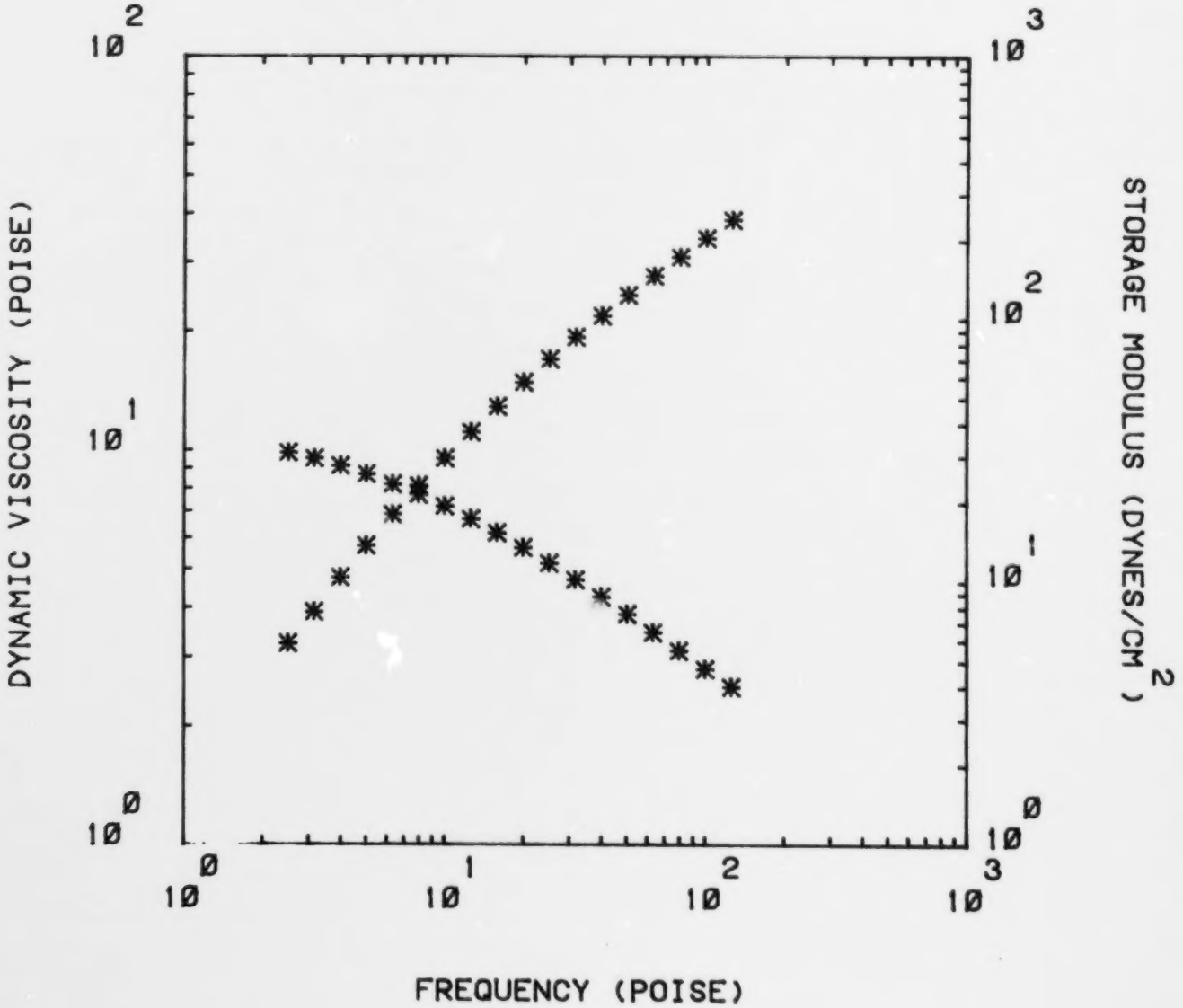
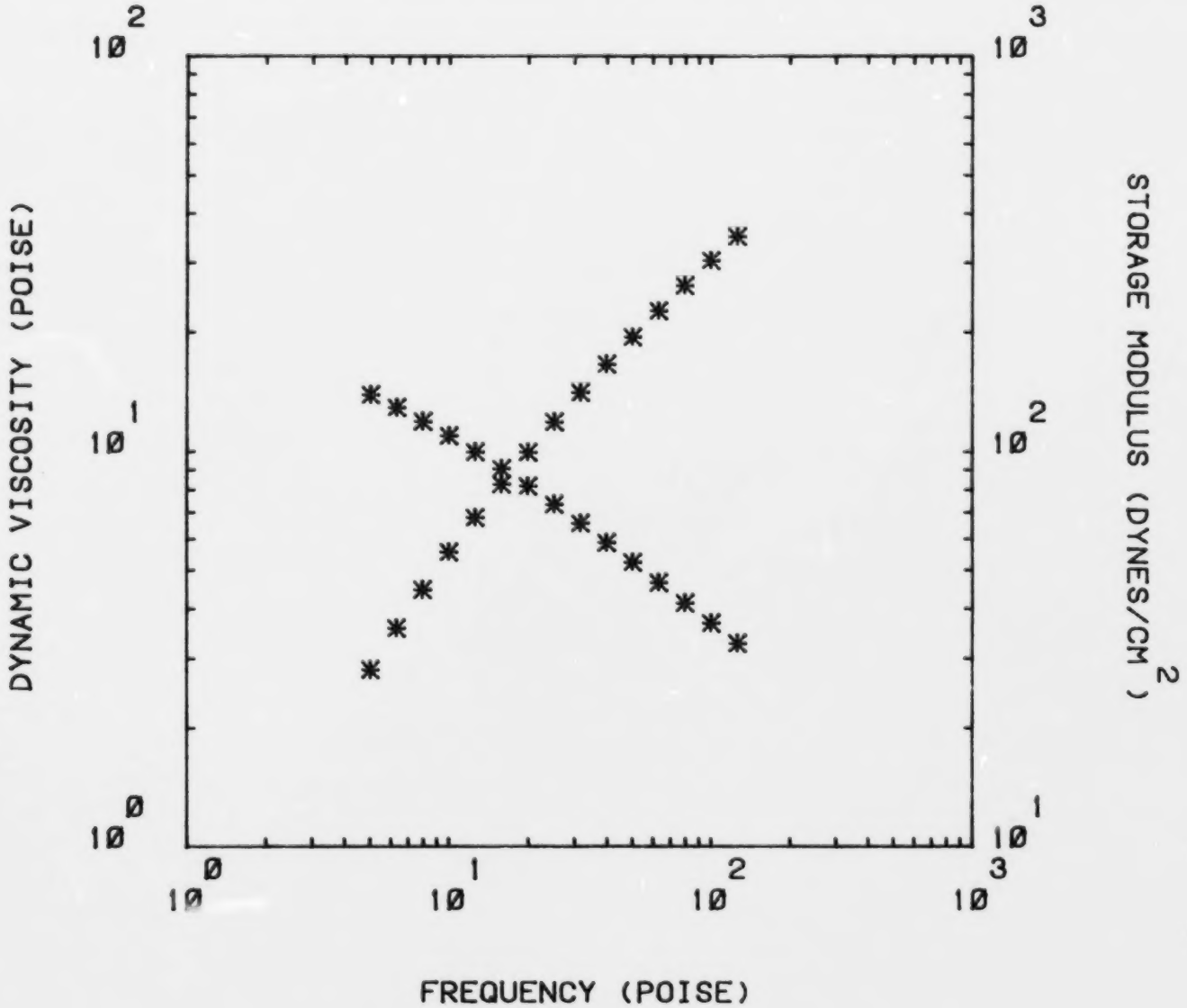


FIGURE 21 DYNAMIC VISCOSITY AND STORAGE MODULUS AS A FUNCTION OF FREQUENCY FOR A 40 G/L SOLUTION OF K125/DPM (SOLUTION 40A)



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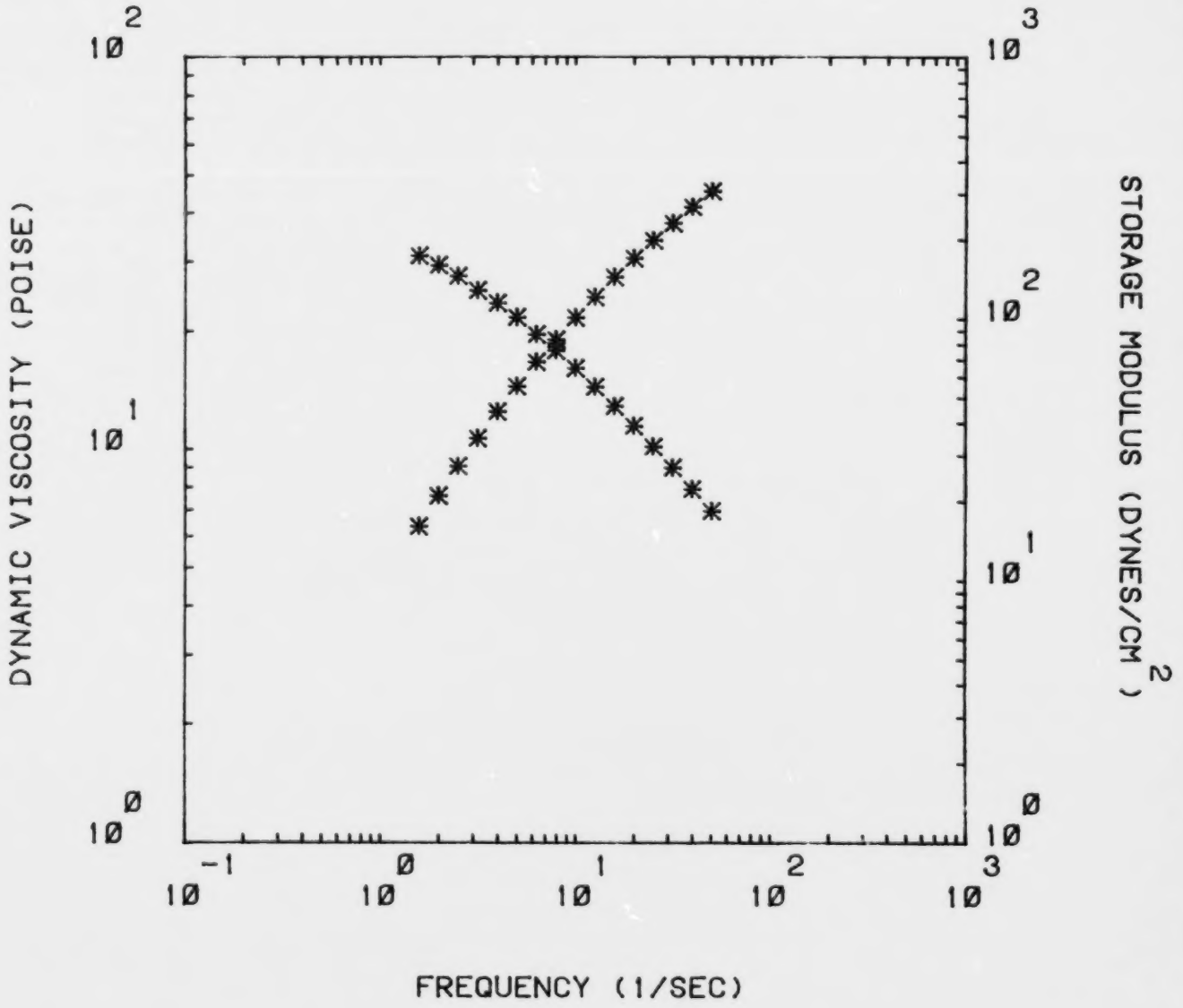


FIGURE 23 DYNAMIC VISCOSITY AND STORAGE MODULUS AS A FUNCTION OF FREQUENCY FOR A 50 G/L SOLUTION OF K125/DPM (SOLUTION 50A)

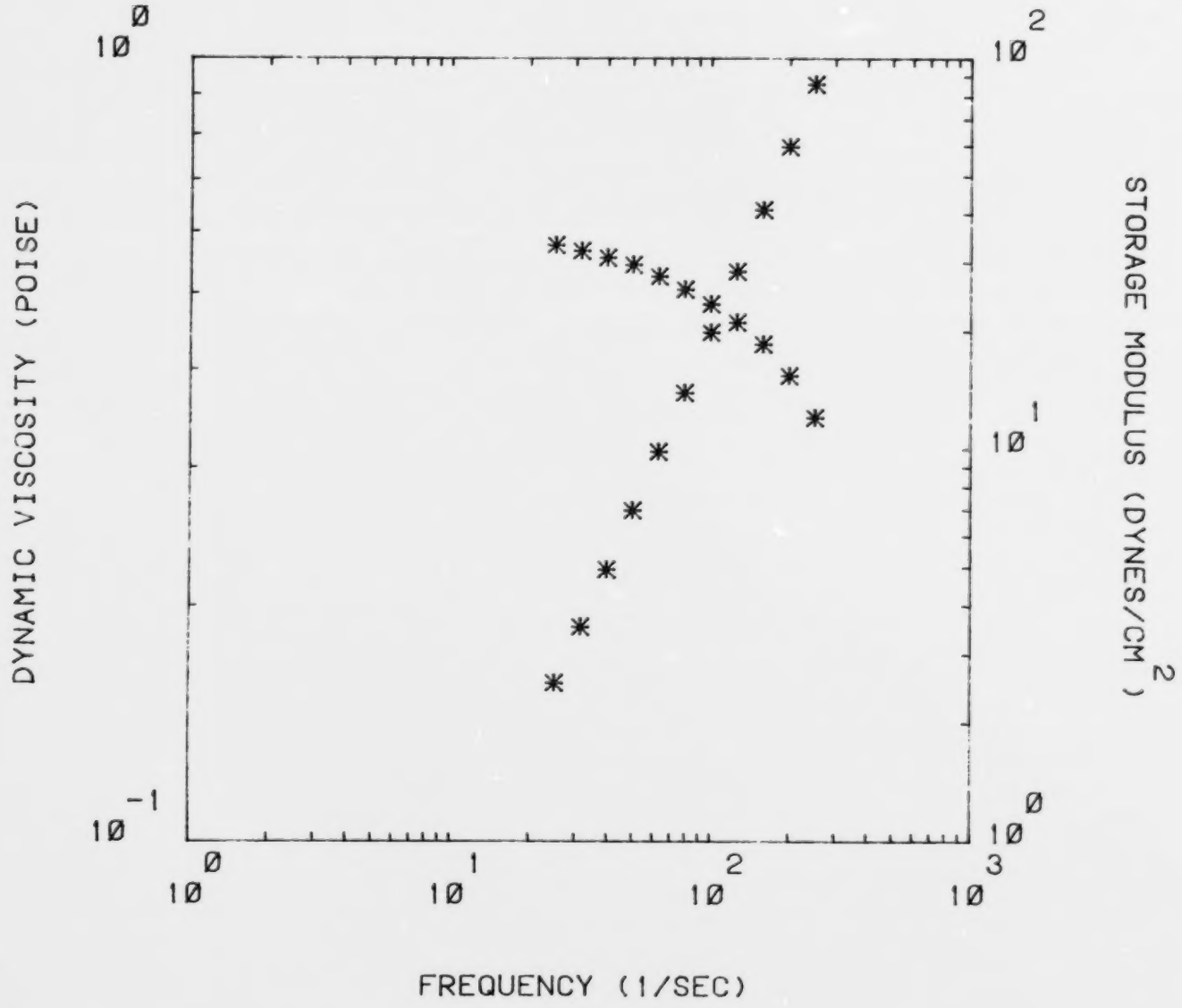


FIGURE 24 DYNAMIC VISCOSITY AND STORAGE MODULUS AS A FUNCTION OF FREQUENCY FOR A 20 G/L SOLUTION OF K125/DPM (SOLUTION 20B)

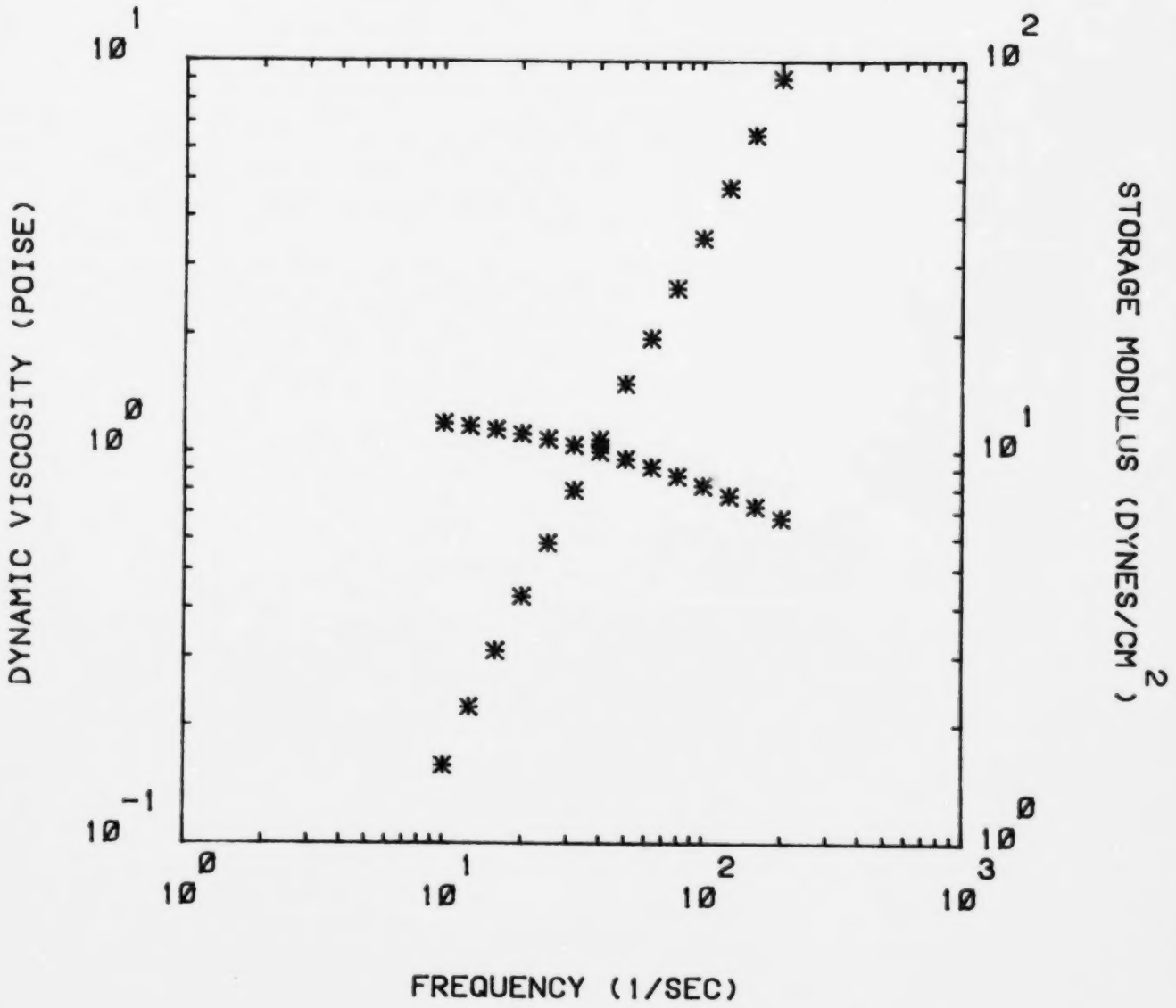


FIGURE 25 DYNAMIC VISCOSITY AND STORAGE MODULUS AS A FUNCTION OF FREQUENCY FOR A 25 G/L SOLUTION OF K125/DPM (SOLUTION 25B)

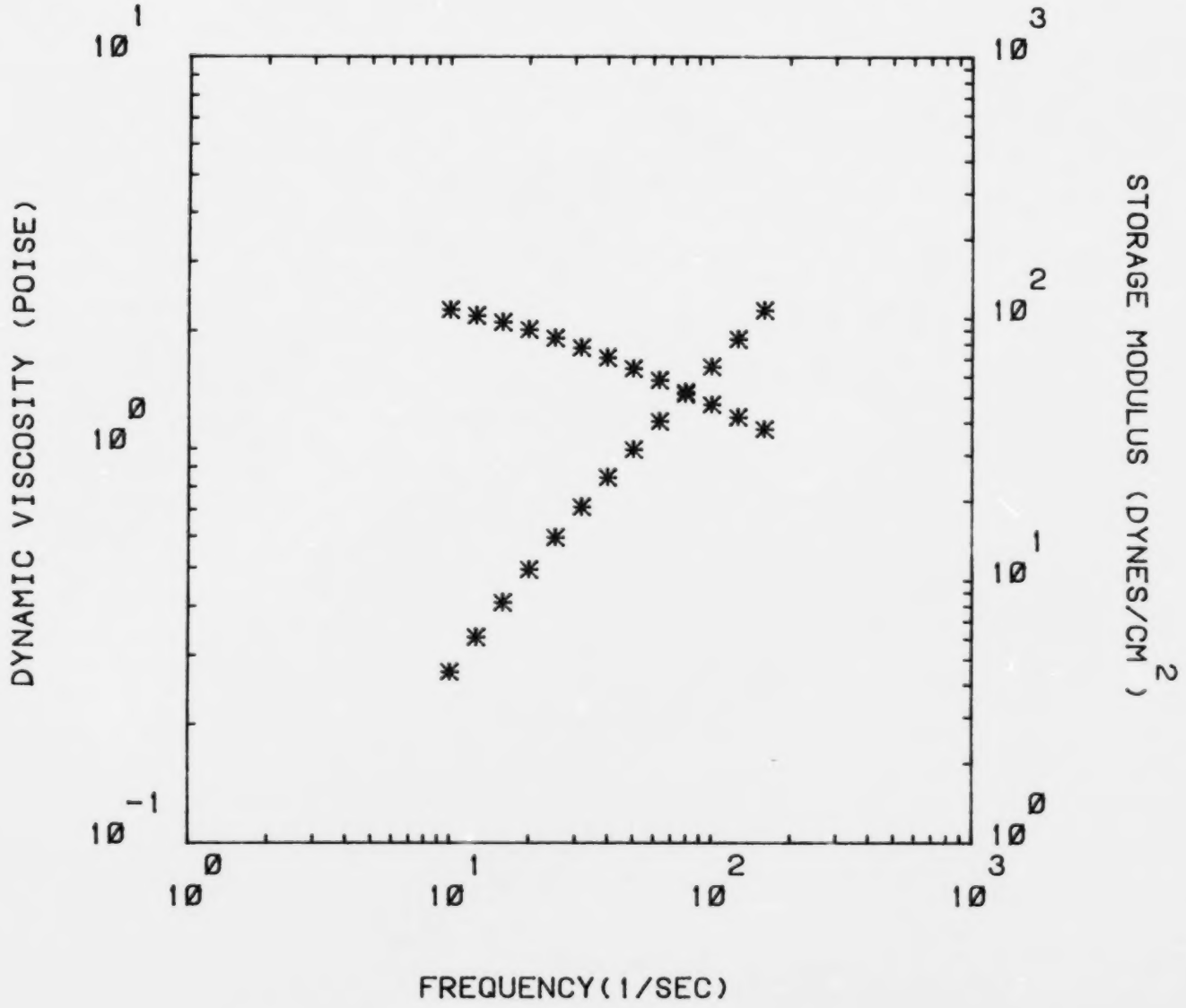


FIGURE 26 DYNAMIC VISCOSITY AND STORAGE MODULUS AS A FUNCTION OF FREQUENCY FOR A 30 G/L SOLUTION OF K125/DPM (SOLUTION 30B)

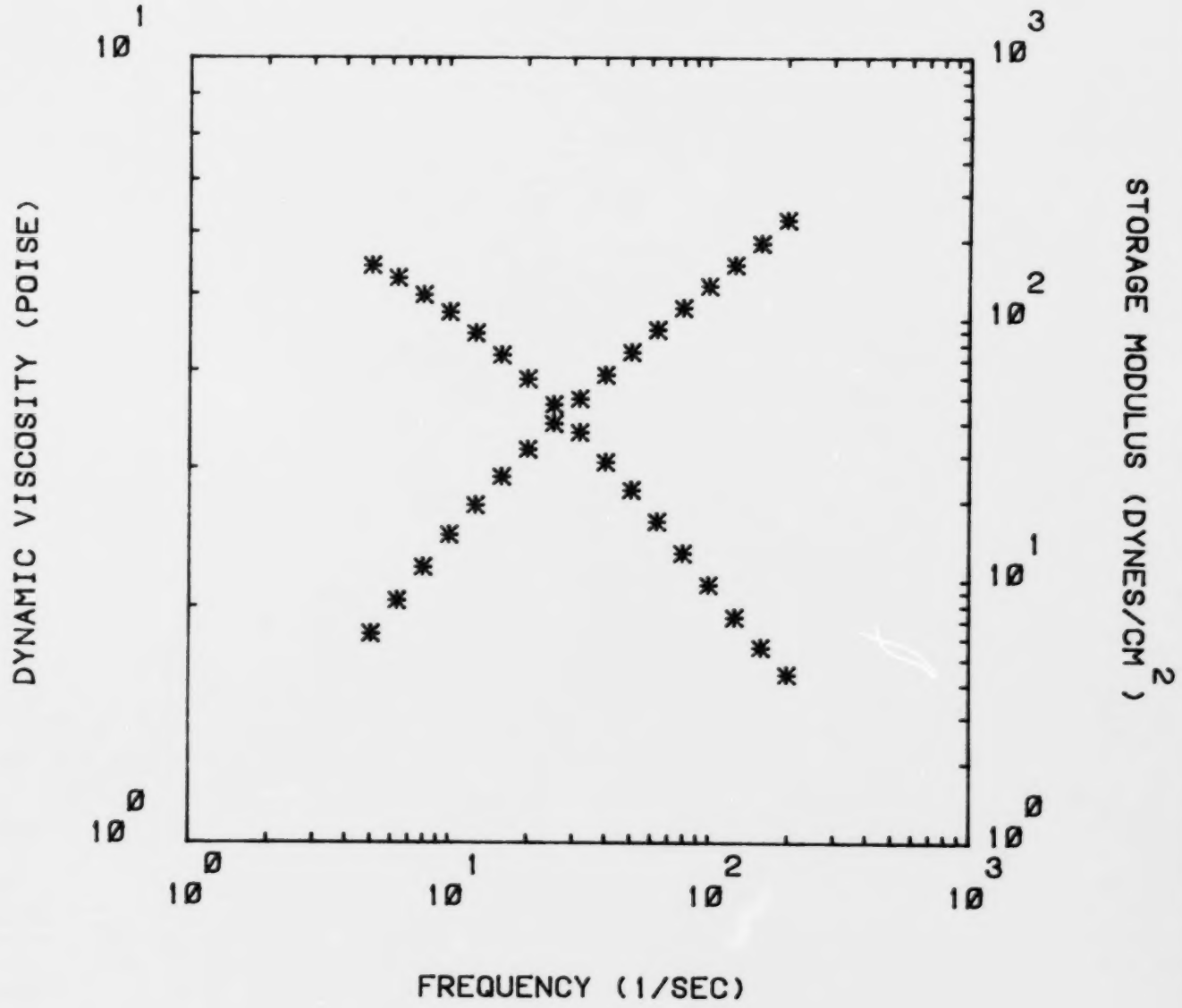
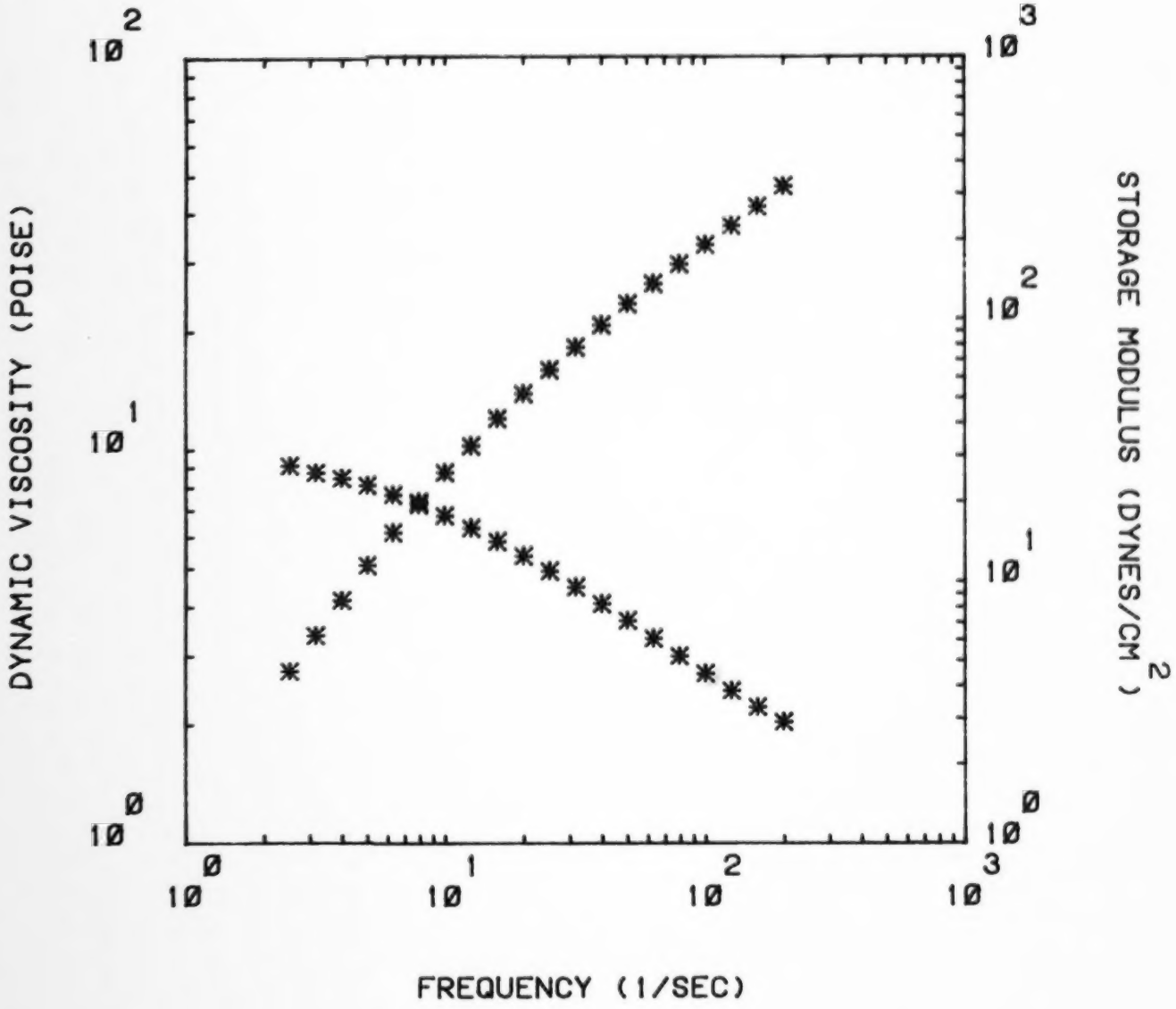


FIGURE 27 DYNAMIC VISCOSITY AND STORAGE MODULUS AS A FUNCTION OF FREQUENCY FOR A 36.3 G/L SOLUTION OF K125/DPM (SOLUTION 36B)



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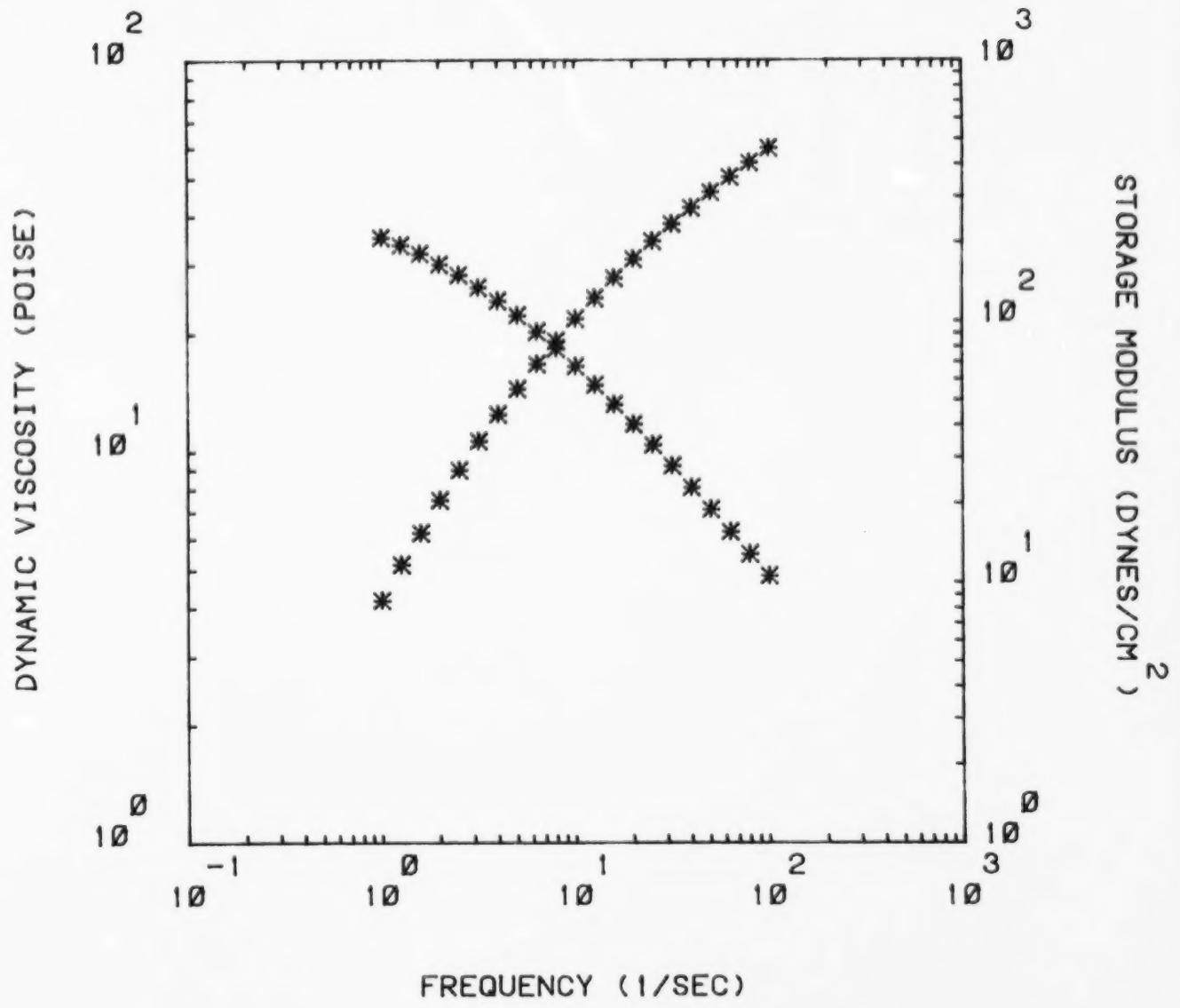

FIGURE 29 DYNAMIC VISCOSITY AND STORAGE MODULUS AS A FUNCTION OF FREQUENCY FOR A 50 G/L SOLUTION OF K125/DPM (SOLUTION 50B)

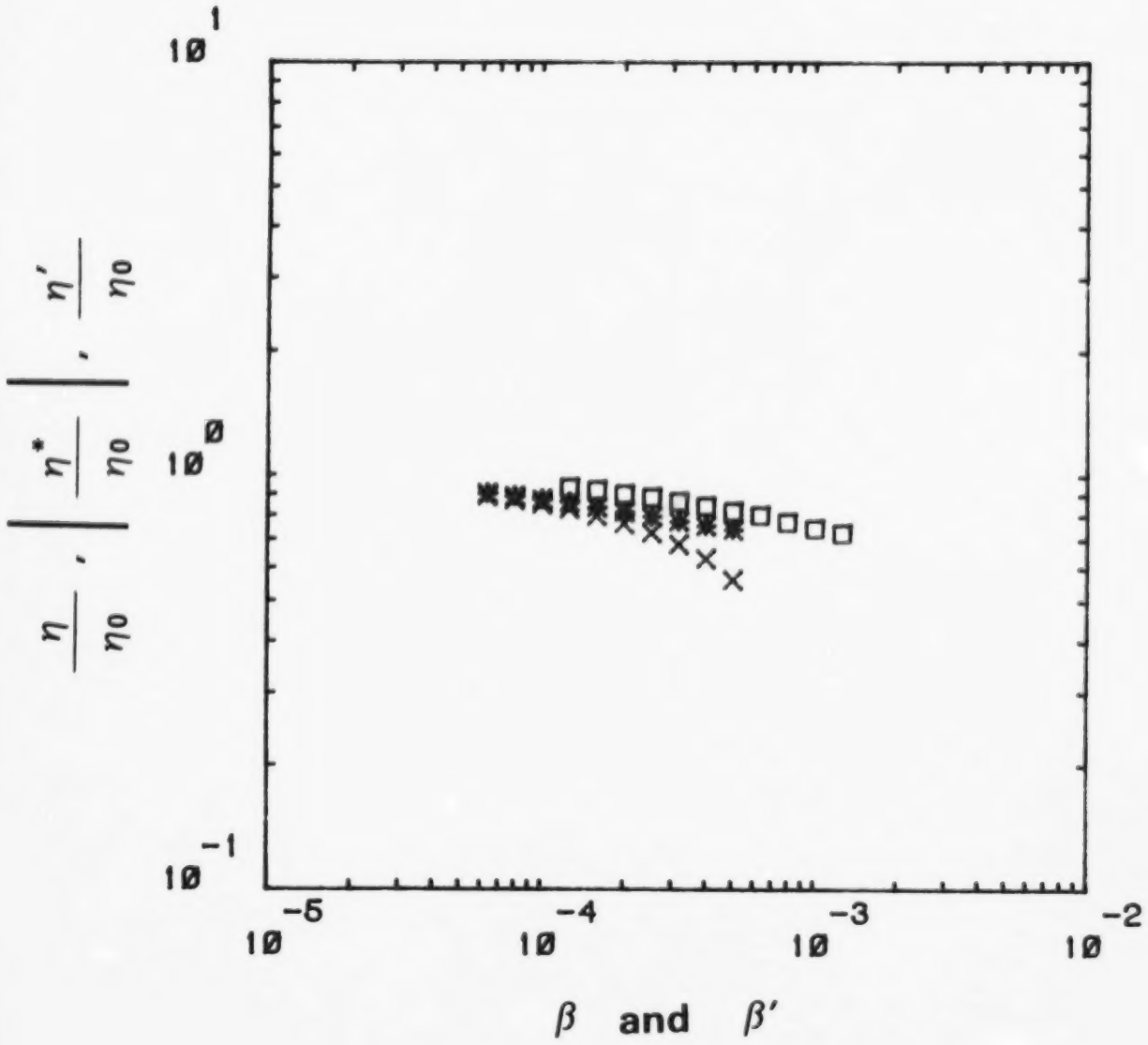

FIGURE 30 REDUCED VISCOSITY □, DYNAMIC VISCOSITY × AND COMPLEX VISCOSITY ✱ AS A FUNCTION OF REDUCED SHEAR RATE AND FREQUENCY FOR A 20 G/L SOLUTION OF K125/DPM (SOLUTION 20A)

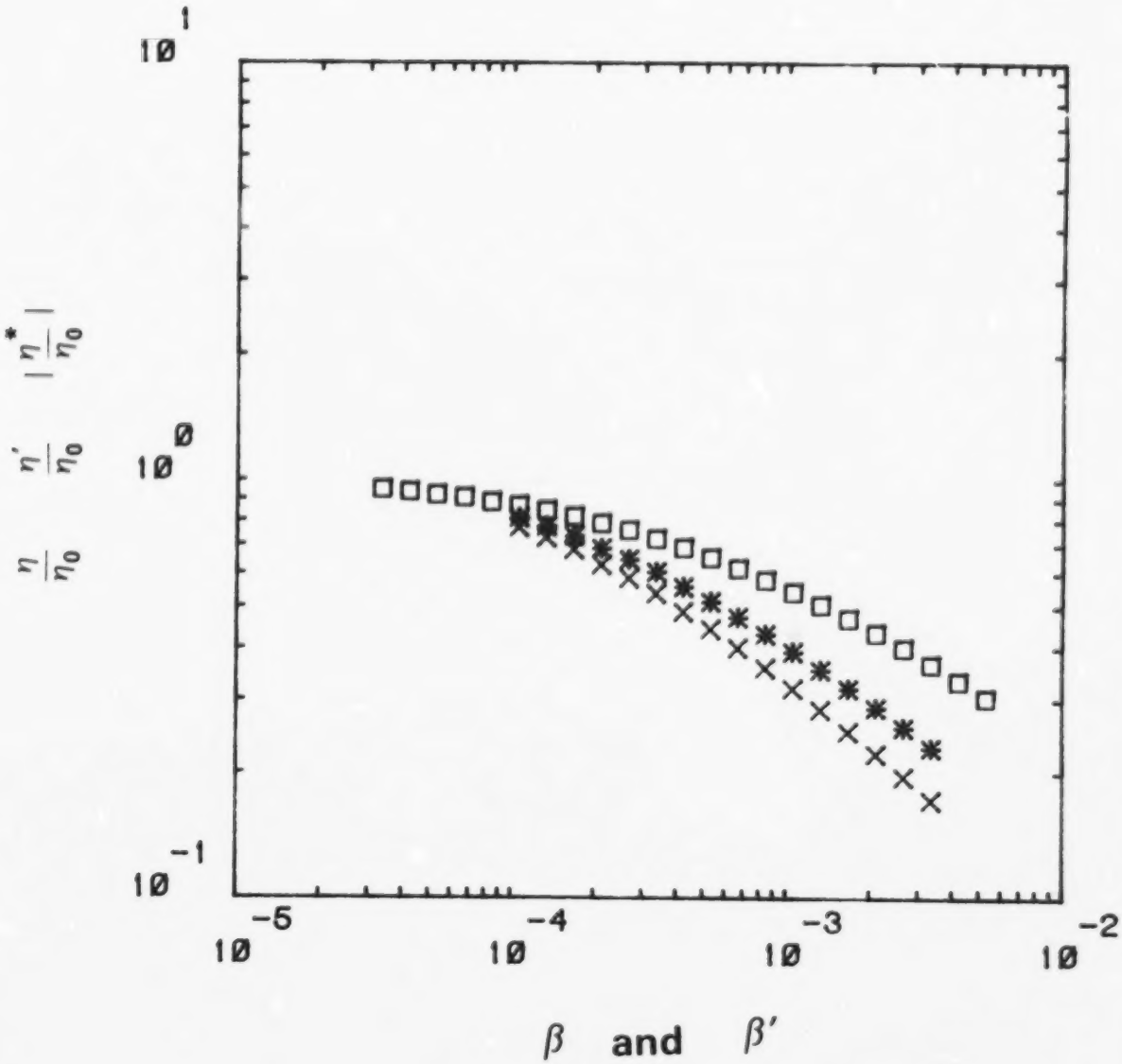

FIGURE 31 REDUCED VISCOSITY □, DYNAMIC VISCOSITY × AND COMPLEX VISCOSITY ✱ AS A FUNCTION OF REDUCED SHEAR RATE AND FREQUENCY FOR A 50 G/L SOLUTION OF K125/DPM (SOLUTION 50A)

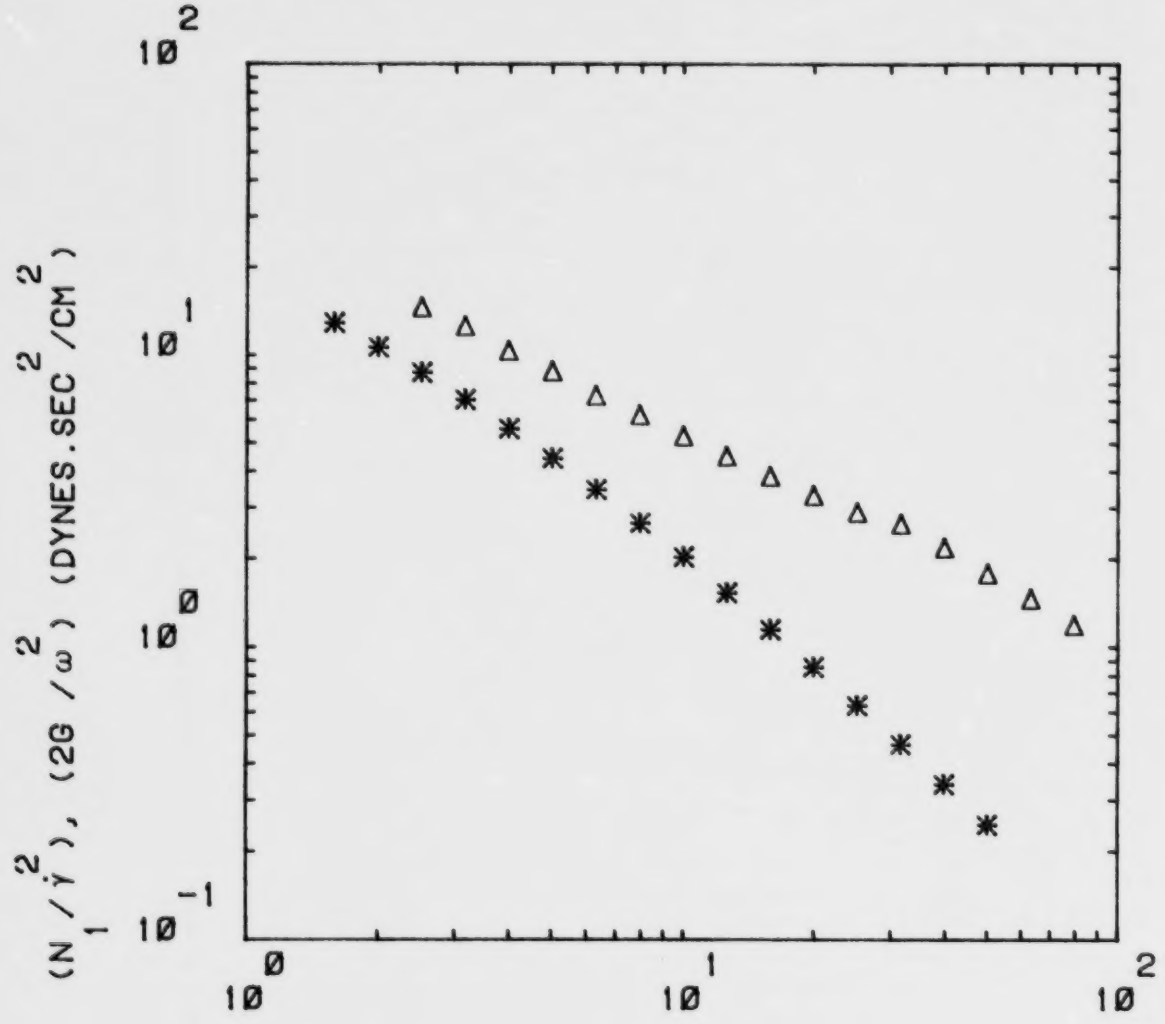

FIGURE 32 $(N_1/\dot{\gamma}^2)$ OR $(2G/\omega^2)$ AS A FUNCTION OF SHEAR RATE OR FREQUENCY FOR A 50 G/L SOLUTION OF K125/DPM (SOLUTION 50A)

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DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1 ORIGINATING ACTIVITY Defence Research Establishment Suffield	2a. DOCUMENT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3 DOCUMENT TITLE

Rheological Properties of Polymer Solutions
Part I: Solutions of K125/DPM

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Suffield Report No. 362 August 1986

5 AUTHOR(S) (Last name, first name, middle initial)

Armour, S.J., Gauthier-Mayer, M.D.

6 DOCUMENT DATE October 1986	7a. TOTAL NO. OF PAGES 121	7b. NO. OF REFS 15
8a. PROJECT OR GRANT NO. S7	9a. ORIGINATOR'S DOCUMENT NUMBER(S) Suffield Report No. 362	
8b CONTRACT NO.	9b. OTHER DOCUMENT NO.(S) (Any other numbers that may be assigned this document)	

10 DISTRIBUTION STATEMENT

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13. ABSTRACT

The rheology of the widely used simulant system, acryloid polymer K125-EA/dipropylene glycol monomethyl ether (DPM), has been investigated in detail using a variety of experimental techniques. Data is given for viscosity as a function of concentration and temperature and for first normal stress difference, storage and loss moduli as functions of concentration at 25°C. Various theoretical relationships between the material parameters are discussed in detail.

KEY WORDS

viscosity
first normal stress difference
dipropylene glycol monomethylether
dynamic viscosity
acryloid polymer

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